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TENSILE AND COMPRESSIVE PROPERTIES OF LAMINATED PLASTICS AT HIGH AND LOW TEMPERATURES

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SUMMARY

The tensile and compressive properties of several types of plastic laminates, which are either in use or have potential application in aircraft structures and parts, were determined at –70°, 77°, and 200° F.

The materials investigated were an unsaturated-polyester laminate with glass fabric as reinforcement and several phenolic laminates with asbestos fabric, high-strength paper, rayon fabric, and cotton fabric as reinforcements. Both high-pressure and low-pressure cotton-fabric phenolic laminates were included.

The tensile strength of all the materials increased 15 to 33 percent with change in the test temperature from 77° F to –70° F and the tensile modulus of elasticity increased 23 to 60 percent. At 200° F all materials except the asbestos-fabric laminate lost 20 to 40 percent of their tensile strength at 77° F and 15 to 30 percent of their tensile modulus of elasticity. The corresponding losses for the asbestos-fabric laminate were 3 and 10 percent, respectively. The glass-fabric laminate had the highest tensile strength and modulus of elasticity of the materials investigated, – namely, 43,000 and 3,000,000 pounds per square inch, respectively.

The compressive strength of all the materials increased 30 to 85 percent at –70° F and the compressive modulus of elasticity increased 10 to 60 percent. At 200° F the compressive strength decreased 10 to 30 percent and the compressive modulus of elasticity 15 to 30 percent. The glass-fabric laminate had the highest compressive strength and modulus of elasticity of the materials investigated, – namely, 42,000 and 3,300,000 pounds per square inch, respectively.

INTRODUCTION

A knowledge of the effect of temperature on the strength properties of plastics is of great importance in application of the materials for aircraft structural purposes. Results obtained by various investigators (references 1 to 5) on plastic materials indicate that large variation in mechanical properties with change in temperature may be expected.

The present investigation was undertaken to obtain the impact-, flexural-, tensile-, and compressive-strength properties of representative laminates in the temperature range -70° to 200° F. Since testing at these temperatures presents many problems not met in testing at room temperature, a major part of the project was concerned with the development of apparatus and techniques. A previous report (reference 6) summarized the results of Izod impact and flexural tests on the selected materials. This report contains the results of tensile and compressive tests made on the same materials and at the same temperatures as the impact and flexural work.

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MATERIALS

The materials selected for testing included commercial grades of high-pressure and low-pressure cotton-fabric phenolic laminates, asbestos-fabric grade AA phenolic laminate, a high-strength-paper phenolic laminate, a rayon-fabric phenolic laminate, two experimental phenolic laminates made under high pressure and low pressure, respectively (in which the same grade C cotton fabric was used as filler), and a glass-fabric laminate bonded with an unsaturated-polyester resin. Grades C and AA are described in A.S.T.M. tentative specification for Laminated Thermosetting Materials (D709-44T).

Samples of five of these laminates were studied at the University of Illinois (reference 7) and the Pennsylvania State College (reference 8) in research investigations of the mechanical properties of the materials. Limited measurements of the tensile and compressive characteristics of the laminates were made at 77° F in both of these projects.

The materials were supplied in nominal $\frac{1}{8}$-inch and $\frac{1}{2}$-inch thicknesses in the form of sheets 3 feet square or larger. A detailed description of the materials is contained in table I.

DEFINITIONS

Tensile strength and compressive strength:

$$\text{Ultimate strength} = \frac{P_m}{bd}$$

where

P_m maximum load

b width of specimen

d thickness of specimen

Secant modulus of elasticity for the stress range 0 to S_1:

$$E = \frac{S_1}{e_1}$$

where e_1 is the strain at stress S_1.

Mean value:

The arithmetic mean of a set of measurements

Standard error of the mean (usually called the standard error if no other statistic is referred to at the same time):

$$S.E. = \sqrt{\frac{{r_1}^2 + {r_2}^2 + {r_3}^2 + \ldots + {r_i}^2 + \ldots + {r_n}^2}{n(n-1)}}$$

where

r_i difference between the i^{th} measurement and mean value

n number of measurements

APPARATUS AND TEST PROCEDURE

The testing procedures outlined in Federal Specification L-P-406a (reference 9) were followed as closely as possible. The specimens, however, were not polished with fine emery paper after machining. The tensile specimens were milled with a machine having a cam-operated milling fixture for duplicating the desired contour. The tensile and compressive specimens of the glass-fabric laminate were machined with carbide-tipped tools. The ends of the compressive specimens were ground.

The tests were made on two Baldwin-Southwark universal hydraulic testing machines of the fluid-support, Bourdon-tube type. Machine A, of 60,000 pounds capacity, had scale ranges of 240, 2400, 12,000, and 60,000 pounds and machine B, of 2400 pounds capacity, scale ranges of 240, 1200, and 2400 pounds. Each machine was located in a room the atmosphere of which was controlled at 77° F and 50-percent relative humidity.

Specimens tested at 77° F and 50-percent relative humidity were conditioned 96 hours prior to the test. Specimens tested at other temperatures were first conditioned in the same manner and then were kept at the testing temperature for 24 ± 2 hours prior to the test. At least five specimens of each sample were tested for each load orientation at each temperature.

TENSILE TESTS

Tensile tests were made according to Method 1011 in Federal Specification L-P-406a, by using the 1200-pound range of machine B and the 2400- and 12,000-pound ranges of machine A. The specimen dimensions were those for Type 1 of Method 1011; the length was 9 inches, the width was 0.75 inch, and the reduced section was $2\frac{1}{4}$ inches long by 0.50 inch wide. Tests to obtain tensile strength and load-elongation graphs were made at -70°, 77°, and 200° F. For the low-temperature and high-temperature tests, the specimen, the grips, and the strain gage were enclosed in an insulated temperature-controlled cabinet (figs. 1 to 3). A triple-paned 12- by 12-inch window in the front, armholes, and interior lights enabled convenient handling of the specimens and equipment. In figure 1 the front of the box has been removed to show the Templin grips, the specimen, and the tensile strain gage. The two holes shown in the rear of the box in figure 1 were used to circulate either hot or cold air from an American Instrument Company conditioning unit shown in figures 2 and 3. Dry ice was used to cool the air; heating was done with electric heaters.

Little difficulty was encountered in the high-temperature testing with this equipment. At low temperatures, frost on the electrical contacts of the gage was washed off with ethyl alcohol. Rusting of the gage and the grips upon removal from the cabinet was avoided by immersing them in alcohol until they attained room temperature. They were then disassembled and dried thoroughly and the grips relubricated.

The tensile strain gage used was a nonaveraging Southwark-Peters Plastics extensometer, model PS-6, with a 2-inch gage length, a strain magnification of 400, and a strain range of 10 percent. This gage separates into two parts and hence was left on the specimen until failure. In all tests the relative rate of head motion was kept constant at 0.05 inch per minute until the specimen failed.

The material used for the tensile tests had a nominal thickness of 1/8 inch (table I). Most of the materials were tested in both lengthwise and crosswise directions at the three temperatures. Tests in the 45° diagonal direction were made at 77° F only. All the tensile specimens for a given material were taken from the same sheet and those for testing at the three temperatures were sampled appropriately from the four quarters of the sheet.

COMPRESSIVE TESTS

The compressive tests were made according to Method No. 1021 in Federal Specification L-P-406a (reference 9) on the 2400-, 12,000-, and 60,000-pound ranges of machine A. Tests to obtain compressive strength and load-compression graphs were made at −70°, 77°, and 200° F. For the low-temperature and high-temperature tests the specimen, the strain gage, and the compression tool were enclosed in an insulated temperature-controlled cabinet. Hot or cold air was supplied to the insulated cabinet from the same conditioning unit as was used for the tensile tests. The problems of frost on the gage contacts and rusting of the apparatus were handled essentially as in the case of tensile testing.

Figure 4 shows the compression tool in the cabinet with the specimen and strain gage in position for testing. The method of supporting and loading the compression tool is indicated in figure 5. The steel supporting and loading blocks are insulated from the platen and crosshead, respectively, by tubular phenolic laminate pieces. A view of the disassembled compression-tool plunger is shown in figure 6.

The compression tool incorporates several features of one designed by Aitchison and Miller (reference 10).

(1) A spherical seat at the bottom of the plunger compensates for specimens with ends nonparallel.

(2) The load is transmitted from the testing machine to the plunger by means of a steel push rod and a spherical bearing at the lower end of the push rod. The upper end of the push rod is a spherical surface concentric with the bearing so that the line of application of the load remains as nearly as possible coaxial with the plunger during a lateral displacement of the heads of the testing machine relative to each other.

(3) The seat for the cylindrical lower bearing block was bored concentric with the plunger bushings. A jig, adjustable for specimens of slightly different thickness, was used to center the specimen on the lower bearing block to approximately 0.01 inch. This made rapid centering of the specimen possible in the high-temperature and low-temperature tests.

An averaging-type Southwark-Peters compressometer, model PC-4, with a gage length of 1 inch, a strain magnification of 1000, and a strain range of 4 percent was used in obtaining stress-strain data. In testing, the relative rate of head motion was 0.01 inch per minute until about 50 percent of the maximum load was attained. Then the strain gage was removed and the rate of loading increased to 0.03 inch per minute.

The compression specimen was 2 inches long and 0.50 inch wide; the thickness (0.45 to 0.60 inch) is given in table I. Compression tests were made for both the lengthwise and crosswise directions of the materials at 77° F but only the lengthwise directions were tested at −70° and 200° F.

For some of the materials, specimens oriented at 45° were tested at 77° F. All the compression specimens for a given material were taken from the same section of the same sheet but were not otherwise sampled since all the specimens were taken from a piece of the sheet less than 1 square foot in area.

An additional set of specimens was tested at 77° F to obtain the strain at failure. A Southwark-Peters deflectometer, model PD-1, was used to measure the motion of the plunger in the compression tool relative to the base of the tool. The deflectometer has low magnifications of 5, 10, and 20 with a range of 2 inches and high magnifications of 50, 100, and 200 with a range of 0.2 inch.

RESULTS AND DISCUSSION

Tensile Properties at Various Temperatures

The results of the tensile tests of the plastic laminates at temperatures of -70°, 77°, and 200° F are shown in table II. Values reported included tensile strength, tensile secant modulus of elasticity for several stress ranges, and total strain at failure. The percentage changes (from the 77° F values) with temperature in the strength and in the secant modulus of elasticity for the lowest stress range are also shown in table II. The variations with temperature of tensile strength and tensile secant modulus of elasticity are shown in figures 7 and 8, respectively. Average tensile stress-strain curves for tests at 77° F of all the laminates are shown in figure 9. Average tensile stress-strain curves for six of the laminates at -70°, 77°, and 200° F are shown in figures 10 to 15.

The tensile properties of representative laminates at 77° F are approximately as follows:

Type of laminate	Tensile strength (10^3 lb/sq in.)	Tensile secant modulus of elasticity[1] (10^6 lb/sq in.)
Grade C phenolic (low-pressure)	9	0.8
Grade C phenolic (high-pressure)	10.5	1.0
Rayon-cotton-fabric phenolic	26(C)[2] and 32(L)[2]	1.6(C)[2] and 1.9(L)[2]
High-strength-paper phenolic	30	2.6
Asbestos-fabric phenolic	5(C)[2] and 8(L)[2]	1.2(C)[2] and 1.5(L)[2]
Glass-fabric unsaturated-polyester	33(C)[2] and 43(L)[2]	2.6(C)[2] and 3.0(L)[2]

[1]Secant modulus for lowest stress range given in table II.
[2](C), crosswise; (L), lengthwise.

The tensile strengths and moduli of elasticity of all the laminates increase at -70° F and decrease at 200° F relative to the 77° F values.

The three cotton-fabric phenolic laminates L1, V1, and W1 exhibit similar changes in tensile-strength properties with change in temperature. The tensile strengths of these materials increase 15 to 25 percent at -70° F and decrease 25 to 30 percent at 200° F compared with the 77° F values. Corresponding changes for the secant modulus of elasticity at 2500 pounds per square inch are increases of about 40 to 50 percent at -70° F and decreases of about 20 to 30 percent at 200° F. Witt, Wolfe, and Rust (reference 11) in tensile tests at 77° F and 160° F on a number of grade C phenolic laminates found average decreases in strength and modulus of elasticity of about 18 and 22 percent, respectively. In making comparisons of data obtained at different laboratories, at least three sources of divergence must be considered: (a) differences between samples, even if made nominally alike, (b) differences in conditioning procedure, and (c) differences in test procedure, apparatus, and preparation of specimens.

The rayon-fabric phenolic laminate Z1 shows the greatest percentage increase (55, crosswise and 70, lengthwise) in tensile modulus of elasticity at -70° F. Other changes in the tensile properties of this laminate are similar to those for the three cotton-fabric phenolic laminates.

The high-strength-paper phenolic laminate S1 shows the largest percentage decrease (40) in tensile strength at 200° F of the laminates tested. The percentage changes in modulus of elasticity at both -70° and 200° F are less for the paper (10 to 20 percent) than for the other four laminates with cellulosic fillers.

Meyer and Erickson (reference 4) reported that the tensile strength and modulus of elasticity for high-strength-paper laminates decreased about 35 and 15 percent, respectively, at 200° F relative to 75° F; these values agree with the data in table II. The changes found by them at subnormal temperatures were much less than those given in the present report and included slight negative values. The material investigated by Meyer and Erickson was quite similar to that tested in this laboratory as regards resin, molding conditions, and paper base. A possible reason for the small changes in both the tensile and compressive moduli of elasticity at -69° F given by Meyer and Erickson is that their tests at the low temperature were made at a different laboratory and with different means of measuring the strain from those made at 75° F and higher temperatures. Hence the uncertainty in the changes they report for low temperatures may be somewhat greater than the uncertainty in corresponding changes obtained in this laboratory, where all tests were made with the same equipment.

The asbestos-fabric laminate with decreases in tensile properties of less than 10 percent at 200° F exhibits the least change of all the materials. Witt, Wolfe, and Rust (reference 11) tested several Grade AA asbestos-fabric phenolic laminates in tension. They found that average decreases in strength and modulus of elasticity at 160° F relative to 77° F were 6 and 15 percent, respectively.

Next to the asbestos-fabric laminate, the glass-fabric laminate AB1 shows the smallest percentage loss (20) in strength at 200° F, which is approximately one-half that of the high-strength-paper laminate S1. The glass-fabric laminate also has the highest percentage increase (33) in tensile strength at -70° F. The percentage change in the tensile modulus of elasticity of the glass-fabric laminate is about the same as for the high-strength-paper laminate at both the high and low temperatures.

The approximate values for the percentage changes in tensile strength and tensile secant modulus of elasticity at -70° and 200° F relative to the value at 77° F for the laminates investigated may be summarized as follows:

Type of laminate	Change in tensile strength		Change in tensile secant modulus of elasticity[1]	
	−70° F (percent)	200° F (percent)	−70° F (percent)	200° F (percent)
Grade C phenolic (low-pressure)	25	−30	47	−18
Grade C phenolic (high-pressure)	20	−30	45	−30
Rayon-cotton-fabric phenolic	25	−25	60	−30
High-strength-paper phenolic	15	−40	23	−15
Asbestos-fabric phenolic	15	−3	23	−10
Glass-fabric unsaturated-polyester (crosswise only)	33	−20	23	−20

[1]Secant modulus for lowest stress range given in table II.

The types of failure obtained in tension were similar to those shown by Findley and Worley (reference 7, fig. 49) and by Marin (reference 8, fig. 41). The cotton-fabric phenolic laminates had a clean break, with the exception of the low-pressure laminate V which also split on a central ply. The high-strength paper had a brittle and slightly jagged break. In the glass-fabric laminate the failure was very irregular and of the tongue-and-groove type, extending throughout the reduced section. The manner of failure in the rayon-fabric laminate was between that of the glass-fabric and the cotton-fabric base laminates.

Compressive Properties at Various Temperatures

The results of the compressive tests of the plastic laminates at temperatures of −70°, 77°, and 200° F are shown in table III. Values reported include compressive strength, compressive secant modulus of elasticity at 2500, 5000, and 7500 pounds per square inch, and total strain at maximum load. The percentage changes (from the 77° F values) with temperature of the compressive strength and modulus of elasticity are also shown in table III. The variations with temperature of the compressive strength and secant modulus of elasticity at 2500 pounds per square inch are shown in figures 16 and 17, respectively. Average compressive stress-strain curves for tests at 77° F of all the laminates are compared in figure 18. Average compressive stress-strain curves for each of six laminates at -70°, 77°, and 200° F are shown in figures 19 to 24.

The compressive properties of the laminates at 77° F are approximately as follows:

Type of laminate	Compressive strength (10^3 lb/sq in.)	Compressive modulus of elasticity[1] (10^6 lb/sq in.)
Grade C phenolic (low-pressure)	19	0.9
Grade C phenolic (high-pressure)	20 to 25	1.1 to 1.3
Rayon-cotton-fabric phenolic	24	1.9(C)[2] and 2.0(L)[2]
High-strength-paper phenolic	19	2.7
Asbestos-fabric phenolic	21	1.2(C)[2] and 1.5(L)[2]
Glass-fabric unsaturated-polyester	36(C)[2] and 42(L)[2]	3.1(C)[2] and 3.3(L)[2]

[1]Secant modulus for stress range 0-2500 lb/in.^{2}
[2](C), crosswise; (L), lengthwise.

The compressive strengths and moduli of elasticity of all the laminates increase at -70° F and decrease at 200° F relative to the 77° F values.

The compressive strengths of the four cotton-fabric base phenolics increase 50 to 70 percent at -70° F and decrease 10 to 30 percent at 200° F. The compressive secant modulus of elasticity increases 30 to 60 percent at -70° F, with the greatest change in the low-pressure materials, and decreases 20 to 30 percent at 200° F. The two low-pressure cotton-fabric phenolic laminates L2 and V2, made with the same resin, show nearly identical variation in compressive properties with temperature. Witt, Wolfe, and Rust (reference 11), who tested a large group of samples of grade C phenolic laminate in compression at 77° and 160° F, found average decreases in compressive strength and modulus of elasticity of about 22 percent and 27 percent, respectively. Norelli and Gard (reference 3), who tested a grade C sample at various temperatures, indicate an increase in compressive strength of about 50 percent at -67° F and a decrease of 35 percent at 167° F relative to 77° F.

The high-strength-paper and the rayon-fabric phenolic laminates increase in strength 85 percent at –70° F and decrease in strength 10 to 20 percent at 200° F. The changes in compressive modulus of elasticity with temperature are less for the high-strength-paper laminate than for the other cellulose-filled laminates, the increase at –70° F being 20 percent and the decrease at 200° F being 15 percent. Corresponding values for the rayon-cotton-fabric phenolic are 45 and 30 percent, respectively. The changes in compressive properties of a high-strength-paper phenolic laminate at –69° F and 200° F relative to 77° F, reported by Meyer and Erickson (reference 4), are in good agreement with the results given in the present report except that they obtained much smaller increases in modulus of elasticity at –69° F.

The asbestos-filled and glass-filled laminates K2 and AB2 in general show much smaller variations in compressive properties with temperature than the cellulose-filled laminates. The changes in compressive strength and modulus of elasticity for the asbestos-fabric phenolic laminate are 30 and 15 percent, respectively, at –70° F, and –10 and –15 percent, respectively, at 200° F. The changes in the glass-fabric laminate are almost the same except for the 30-percent loss in compressive strength at 200° F.

The compressive-strength variation with temperature of the Grade AA asbestos-fabric laminate reported by Norelli and Gard (reference 3) agrees in trend with but differs in magnitude from the data in table III. They obtained an increase of less than 10 percent at –67° F and a decrease of 25 percent at 167° F. No comparative data were found in the literature for a glass-fabric laminate similar to the sample AB1.

The approximate values for the changes in compressive strength and modulus of elasticity at –70° and 200° F relative to the value at 77° F for lengthwise specimens are as follows:

Type of laminate	Change in compressive strength		Change in compressive secant modulus of elasticity (0 to 2500 lb/sq in.)	
	−70° F (percent)	200° F (percent)	−70° F (percent)	200° F (percent)
Grade C phenolic (low-pressure)	50	−10	60	−20
Grade C phenolic (high-pressure)	50 to 70	−15 to −30	30 to 45	−25 to −30
Rayon-cotton-fabric phenolic	85	−10	45	−30
High-strength-paper phenolic	85	−20	20	−15
Asbestos-fabric phenolic	30	−10	15	−15
Glass-fabric unsaturated-polyester	30	−30	10	−15

All the cotton-fabric laminates, the asbestos-fabric laminates, and the rayon-fabric laminates failed in the same manner. The break started at the top of the specimen at one edge and went downward across the machined face at an angle between 45° and 60° to the horizontal. A similar failure occurred in the low-pressure cotton-fabric laminate except that there was splitting along a central ply. The line of failure in the high-strength-paper laminate progressed from one corner to a diagonally opposite corner partly at a 45° angle and partly by delamination. The glass-fabric laminate failed explosively and delaminated at several places. Examples of broken compression specimens of similar laminates are shown by Findley and Worley (reference 7, fig. 50) and by Marin (reference 8, fig. 42).

Comparison of Temperature Dependence of Flexural, Tensile, and Compressive Properties

Table IV and figure 25 show the percentage changes in strength and modulus of elasticity with temperature for flexural (data from reference 6), tensile, and compressive tests.

For the cellulose-filled laminates, the percentage changes in tensile and flexural strength with temperature for a given sample are about the same. These strength values increase 15 to 25 percent at -70° F and decrease 25 to 40 percent at 200° F. The compressive strength behavior of the cellulose-filled materials is different; the increases at -70° F are 50 to 85 percent; the decreases at 200° F are only 10 to 30 percent. For a given laminate the percentage increase in compressive strength at -70° F is at least double the percentage increase in flexural or tensile strength; at 200° F the compressive-strength loss in percent in general is one-half the percentage loss in flexural or tensile strength.

The increases in the three moduli of elasticity of the five cellulose-fabric laminates at -70° F are about 40 to 60 percent, and the decreases in moduli of elasticity at 200° F are from 15 to 30 percent. The high-strength-paper laminate, the three moduli of which change very similarly (fig. 25), shows smaller changes in moduli at -70° F than the other cellulose-filled phenolics.

The percentage changes in flexural, tensile, and compressive strength of the asbestos-fabric phenolic laminate are 15 to 30 percent at -70° F and about -5 percent at 200° F. The changes in the three strength values for the glass-fabric laminate are nearly alike, particularly at -70° F. The behavior of the strength properties of the mineral-filled laminates is in contrast with that of the cellulose-filled laminates, for which the variation in compressive strength is much different from that in flexural and tensile strength.

The respective increases in the flexural, tensile, and compressive moduli of the glass-fabric laminates at -70° F are almost equal to the decreases at 200° F. The changes in flexural and compressive moduli are very nearly 12 percent; the tensile-modulus changes are 22 percent. The variations with temperature for the three moduli of elasticity of the asbestos-fabric material differ; the changes at 200° F are smaller and in the reverse order of those at -70° F.

In examining the behavior of the materials at elevated temperatures the effect of the conditioning period must be considered. Heating the laminates may cause further cure of the resin and diminish the moisture content. In the previous work on flexural properties of the laminates (reference 6) it was found that the flexural properties increased for some laminates and decreased for others after heating for 24 hours at 200° F (when tested at 77° F). The effect of heating may be different for the tensile, flexural, and compressive properties. Moreover, the effect of heating may vary among various laminates. Thus, the flexural strengths of all the cellulose-filled laminates decreased 7 to 15 percent as a result of the heating; the two mineral-filled laminates, however, increased 8 percent in flexural strength after heating (reference 6, table VI).

The effect of high humidity combined with a temperature of 150° F on the flexural strengths of the laminates was determined in work previously reported (reference 6). Two phenolic laminates, the high-strength-paper material S2 and a low-pressure grade C product V2 suffered the greatest loss in strength of the materials tested. It seems quite probable that, if tensile and compressive tests were made at high temperature and humidity, some of the laminates, such as the S2 and V2 materials, would be considerably weakened.

Variation of Strength Properties of Laminates with Orientation of Specimen

Table V and figures 26 to 29 give comparative data for tensile and compressive properties of the laminates in lengthwise, crosswise, and 45° orientations.

In all laminates the compressive strength varies less with direction than the tensile strength. The compressive strengths for the three directions of test differ by 10 percent or less except for the glass-fabric laminate, the compressive strength of which in the 45° diagonal direction is only 60 percent of that in the lengthwise direction. Moreover, except for the glass-fabric laminate, the compressive strengths of the laminates are within 10 percent of 21,000 pounds per square inch; the tensile strengths of these same laminates (excluding the glass-fabric laminate) range from 5,000 to 32,000 pounds per square inch.

The relative constancy of compressive strength with variation of direction and reinforcement indicates that the strength of the resin is the major factor in determining the compressive strength of fabric and paper-base laminates. This conclusion was reached by Erickson and Mackin (reference 12; see p. 268 and tables 1 and 2) in regard to a parallel-ply high-strength-paper laminate.

In general, the tensile strength and the tensile and compressive secant moduli of elasticity of the cotton-fabric and the high-strength-paper phenolic laminates show small variations with the direction of test. The diagonal values are about 10 to 20 percent lower than the other values.

The rayon-fabric and the glass-fabric laminates show large variations in tensile strength and tensile and compressive moduli with the direction of test. The diagonal values are as low as 30 to 50 percent of the lengthwise values. The rayon-fabric laminate, although a crossed-ply laminate, shows the greatest difference between the lengthwise and crosswise values of tensile strength and tensile modulus of elasticity. This may be explained as follows: The rayon fabric, of higher strength and modulus of elasticity than the resin, is practically unidirectional with regard to strength. In the $\frac{1}{8}$-inch thickness there are four plies lengthwise to three crosswise. If the modulus of elasticity of the resin, small compared to that of the fabric, is neglected, the ratio of lengthwise to crosswise tensile modulus of elasticity should be 1.33; the measured ratio is 1.18. Application of the same idea to the compressive moduli for 23-ply material indicates a corresponding ratio of 1.09; the measured ratio is 1.07.

In the asbestos-fabric laminate, a parallel-ply material, the tensile strength and the tensile and compressive moduli are greatest in the lengthwise, least in the crosswise, and intermediate in the diagonal directions.

Strain at Failure

Except for the asbestos-fabric laminate, the elongation at failure in tension is about the same for the lengthwise and crosswise directions. It is greatest for the 45° diagonal direction. The greatest elongations in tension are those of the two low-pressure laminates L and V and the glass-fabric laminate in the 45° diagonal direction.

Table V also shows that in compression the maximum strain at failure occurs in the 45° diagonal direction. In general, the strain at failure in compression is greater than in tension for the same material and orientation of specimen.

The elongation in tension (table II) for the cellulose-filled laminates is greater at 77° F than at either -70° or 200° F. The deflection at failure in flexural testing (reference 6) is greater at 77° F than at either -70° or 200° F for the six cellulose-filled laminates. Meyer and Erickson (reference 4) have shown that the elongation at failure in tension of a high-strength-paper laminate increases directly with the moisture content of the laminate. Therefore, part of the increase in brittleness of the cellulose-filled materials at 200° F may be due to the decrease in moisture content of the laminates caused by 24 hours of conditioning at 200° F.

CONCLUSIONS

From tensile and compressive tests of several types of plastic laminates, the following conclusions may be drawn:

1. The tensile and compressive strengths and moduli of elasticity of all laminates increase at low temperature and decrease at high temperature relative to the values at 77° F.

2. For all laminates except the asbestos-fabric phenolic laminate, the tensile and compressive strengths at 200° F are approximately one-half of the corresponding values at -70° F. The changes in the strength values of the asbestos-filled product are much smaller and less than for any other laminate.

3. For the cellulose-filled laminates, the increase in compressive strength at the low temperature is much greater in magnitude than the decrease at the high temperature; the tensile-strength variation, however, is less at the low temperature than at the high temperature. The tensile and flexural strengths of these materials exhibit similar temperature changes.

4. The tensile and compressive moduli of all materials increase more at the low temperature than they decrease at the high temperature. Except for the high-strength-paper laminate, the over-all changes are greater for the cellulose-filled than for the mineral-filled laminates. The high-strength-paper, asbestos-fabric, and glass-fabric laminates show about the same over-all percentage variation of tensile and compressive moduli with temperature.

5. The tensile strengths of the high-strength-paper, rayon-fabric, and glass-fabric laminates are about three times greater than those of the cotton-fabric and asbestos-fabric phenolics.

6. The glass-fabric laminate is outstanding in compressive strength; at 77° F its strength is 36,000 and 42,000 pounds per square inch, respectively, in the crosswise and lengthwise directions. The compressive strength of the other laminates is 21,000 pounds per square inch within about 10 percent.

7. The tensile and compressive moduli of elasticity of the glass-fabric and high-strength-paper laminates are greater than for the other materials at all temperatures and are in the range of 2,600,000 to 3,300,000 pounds per square inch.

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Washington, D.C., March 7, 1947

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TABLE I.– DESCRIPTION OF MATERIALS

NBS designation	Type of laminate	Density (gm/cm^3)	Average thickness (in.)	Manufacturer	Resin		Reinforcement					Molding conditions			
					Type	Content by weight (percent)	Type	Thread count		Number of plies	Ply Arrangement	Pressure (lb/sq in.)	Temperature (°F)	Time of heating (min)	Time of cooling (min)
								Warp	Filling						
L1 L2	Low-pressure cotton-fabric phenolic	1.36 1.32	0.15 .60	Bakelite Corporation	Bakelite BV-16887	52	Enameled duck (8 oz/yd^2)	84	28	9 35	Cross	250	325	30	
V1 V2	Low-pressure grade C phenolic	1.27 1.29	.15 .55	Synthane Corporation	Bakelite BV-16887	51	Army duck (10.4 oz/yd^2)	50	40	7 [a]26	Cross	180	320	50	
W1 W2	High-pressure grade C phenolic	1.36 1.36	.14 .45	Synthane Corporation	Bakelite BV-1112	47	Army duck (10.4 oz/yd^2)	50	40	7 25	Cross	1800	320	50	
I2	Grade C phenolic	1.34	.53	Synthane Corporation	Bakelite BV-1112	48	Cotton fabric	50	40	27	Parallel	1800	340 ± 20	50	20
Z1 Z2[b]	Rayon-cotton-fabric phenolic	1.37 1.37	.16 .48	Formica Insulation Company	Ironsides Company phenolic 91-L	37 to 40	Fortisan (12.5 oz/yd^2)	Rayon 75	Cotton 12	7 23	Cross	1100	300	20	20
S1 S2	High-strength-paper phenolic	1.42 1.42	.12 .50	Consolidated Water Power and Paper Company	Bakelite 16526	30	High-strength Mitscherlich paper	-----	------	27 per 0.060-inch thickness	Cross	250	310 ± 10	12 30	
K1 K2	Asbestos-fabric phenolic	1.50 1.48	.15 .57	Synthane Corporation	Bakelite 2427	47	Asbestos fabric (18 oz/yd^2)	18	16	5 20	Parallel	1800	340 ± 20	50	20
AB1	Glass-fabric unsaturated-polyester	1.82	.13	Army Air Forces Technical Service Command	Plaskon 900	43	Fiberglas ECC-11-112			45	Parallel	40	180 220	120 120	
AB2	---------do----------	1.86	.49	------do------	--do--					166	---do---	40	160 180 200 220	120 120 120 120	

[a]Warp directions at right angles in the two face plies.

[b]The $\frac{1}{2}$-inch-thick sample, received 10 months later than the $\frac{1}{8}$-inch sample above, was made similar in construction to the $\frac{1}{8}$-inch material. Sample Z2 in NACA TN No. 1054 was received at the same time as the $\frac{1}{8}$-inch material.

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TABLE II.- TENSILE PROPERTIES OF LAMINATED PLASTICS AT VARIOUS TEMPERATURES

Material designation	Orientation of specimen	Test temperature (°F)	Tensile strength: Mean (10^3 lb/sq in.) (1)	Tensile strength: Change (percent) (2)	Tensile secant modulus of elasticity for various ranges of stress: Mean (10^6 lb/sq in.) (1)	Change (percent) (2)	Mean (10^6 lb/sq in.) (1)	Mean (10^6 lb/sq in.) (1)	Total strain at failure (percent)
					0 to 2500 lb/sq in.		0 to 5000 lb/sq in.		
L1, low-pressure cotton-fabric phenolic	Lengthwise	-70	13.2 ± 0.3	13	1.33 ± 0.02	39	1.27 ± 0.03		2.9
		77	11.7 ± .3		.96 ± .01		.85 ± .01		4.9
		200	8.6 ± .1	-26	.76 ± .02	-21	.65 ± .01		4.2
	Crosswise	-70	13.0 ± .2	17	1.45 ± .05	38	1.38 ± .03		3.3
		77	11.2 ± .2		1.05 ± .04		.86 ± .02		4.8
		200	8.5 ± .3	-24	.79 ± .01	-25	.63 ± .01		3.2
V1, low-pressure grade C phenolic	Lengthwise	-70	11.1 ± .1	25	1.25 ± .07	49	1.09 ± .06		3.9
		77	8.9 ± .1		.84 ± .02		.64 ± .03		4.8
		200	6.1 ± .1	-31	.69 ± .01	-18	.21 ± .01		3.7
	Crosswise	-70	10.9 ± .2	24	1.18 ± .04	45	1.04 ± .08		3.9
		77	8.8 ± .1		.81 ± .01		.51 ± .05		5.0
		200	5.9 ± .1	-31	.66 ± .01	-19	.19 ± .01		3.6
W1, high-pressure grade C phenolic	Lengthwise	-70	12.4 ± .1	20	1.47 ± .07	40	1.39 ± .05		3.3
		77	10.3 ± .1		1.05 ± .03		.91 ± .03		3.7
		200	7.3 ± .2	-29	.77 ± .02	-27	.60 ± .04		2.8
	Crosswise	-70	12.5 ± .1	21	1.55 ± .07	48	1.40 ± .05		3.0
		77	10.3 ± .3		1.05 ± .01		.93 ± .02		4.8
		200	7.2 ± .1	-30	.78 ± .04	-32	.56 ± .01		2.5
					0 to 5000 lb/sq in.		0 to 10,000 lb/sq in.	0 to 15,000 lb/sq in.	
Z1, rayon-cotton-fabric phenolic	Lengthwise	-70	40.8 ± .7	26	3.20 ± .03	71	2.72 ± .02	2.44 ± 0.02	2.8
		77	32.4 ± .1		1.87 ± .02		1.64 ± .01	1.27 ± .01	4.0
		200	24.4 ± .3	-25	1.38 ± .02	-26	1.10 ± .01	.87 ± .01	3.4
	Crosswise	-70	31.9 ± .3	26	2.43 ± .16	54	1.98 ± .11	1.71 ± .07	3.0
		77	25.5 ± .3		1.58 ± .02		1.24 ± .01	.87 ± .01	3.9
		200	18.4 ± .3	-28	.98 ± .02	-38	.67 ± .01	.57 ± .01	3.4
S1, high-strength-paper phenolic	Lengthwise	-70	35.2 ± .9	19	3.18 ± .06	22		3.10 ± .07	1.2
		77	29.7 ± .5		2.61 ± .02			2.40 ± .03	1.7
		200	17.6 ± .4	-41	2.09 ± .03	-20		1.70 ± .02	1.1
	Crosswise	-70	35.0 ± .9	14	3.22 ± .06	24		3.15 ± .07	1.3
		77	30.8 ± .2		2.59 ± .02			2.37 ± .04	1.7
		200	18.0 ± .4	-42	2.36 ± .03	-9		1.79 ± .02	1.1
					0 to 2500 lb/sq in.		0 to 5000 lb/sq in.		
K1, asbestos-fabric phenolic	Lengthwise	-70	9.9 ± .2	21	1.72 ± .10	16	1.55 ± .09		2.1
		77	8.2 ± .2		1.48 ± .05		1.30 ± .03		1.8
		200	8.0 ± .3	-2	1.34 ± .03	-9	1.23 ± .05		1.2
	Crosswise	-70	5.4 ± .1	8	1.49 ± .08	30			.5
		77	5.0 ± .2		1.15 ± .02				.6
		200	4.8 ± .2	-4	1.02 ± .04	-9			.5
					0 to 5000 lb/sq in.		0 to 10,000 lb/sq in.	0 to 15,000 lb/sq in.	
AS1, glass-fabric unsaturated-polyester	Lengthwise	77	42.9 ± 1.0		3.03 ± .07		2.78 ± .06	2.66 ± .05	1.8
	Crosswise	-70	44.4 ± .4	33	3.24 ± .16	23	3.00 ± .10	2.73 ± .07	2.2
		77	33.3 ± 1.5		2.63 ± .15		2.41 ± .12	2.25 ± .10	1.7
		200	26.4 ± .1	-21	2.08 ± .08	-21	1.93 ± .06	1.79 ± .07	1.7

[1]Mean value for five to ten specimens. The accompanying plus or minus value is the standard error S.E.
[2]Relative to 77° F value.

TABLE III.– COMPRESSIVE PROPERTIES OF LAMINATED PLASTICS AT VARIOUS TEMPERATURES [1]

Material designation	Compressive strength			Compressive secant modulus of elasticity for various ranges of stress				Total strain (percent) (4)
	Test Temperature (°F)	Mean (10^3 lb/sq in.) (2)	Change (percent) (3)	Mean (10^6 lb/sq in.) (2)	Change (percent) (3)	Mean (10^6 lb/sq in.) (2)	Mean (10^6 lb/sq in.) (2)	
				0 to 2500 lb/sq in.		0 to 5000 lb/sq in.	0 to 7500 lb/sq in.	
L2, low-pressure cotton-fabric phenolic	–70	33.8 ± 0.6	54	1.47 ± 0.02	58	1.38 ± 0.02	1.26 ± 0.01	
	77	22.0 ± .1		.93 ± .01		.74 ± .01	.59 ± .01	12.2
	200	20.5 ± .1	–7	.72 ± .02	–23	.56 ± .01	.44 ± .01	
V2, low-pressure grade C phenolic	–70	29.1 ± .6	50	1.39 ± .02	62	1.30 ± .01	1.18 ± .01	
	77	19.4 ± .5		.86 ± .01		.71 ± .01	.58 ± .01	10.5
	200	17.3 ± .5	–11	.67 ± .01	–22	.54 ± .01	.44 ± .01	
W2, high-pressure grade C phenolic	–70	31.3 ± .3	53	1.54 ± .02	44	1.49 ± .02	1.41 ± .02	
	77	20.4 ± .2		1.07 ± .01		.90 ± .01	.71 ± .01	8.6
	200	17.2 ± .2	–16	.81 ± .01	–24	.63 ± .01	.48 ± .01	
I2, grade C phenolic	–70	41.9 ± .4	70	1.68 ± .02	32	1.62 ± .02	1.55 ± .01	
	77	24.7 ± .1		1.27 ± .02		1.19 ± .01	1.08 ± .01	
	200	17.2 ± .2	–30	.89 ± .01	–30	.72 ± .01	.60 ± .01	12.0
Z2, rayon-cotton-fabric phenolic	–70	46.1 ± .3	86	2.97 ± .03	46	2.82 ± .02	2.74 ± .04	
	77	24.8 ± .1		2.03 ± .01		1.94 ± .01	1.80 ± .01	5.7
	200	22.3 ± .4	–10	1.46 ± .01	–28	1.35 ± .01	1.09 ± .02	
S2, high-strength-paper phenolic	–70	35.4 ± .6	84	3.27 ± .04	22	3.16 ± .04	3.02 ± .04	
	77	19.2 ± .1		2.68 ± .02		2.57 ± .01	2.41 ± .01	4.5
	200	14.9 ± .1	–22	2.22 ± .04	–17	2.03 ± .03	1.66 ± .01	
K2, asbestos-fabric phenolic	–70	25.7 ± .8	29	1.79 ± .02	16	1.70 ± .01	1.59 ± .01	
	77	19.9 ± .2		1.55 ± .05		1.38 ± .02	1.21 ± .02	5.1
	200	18.3 ± .1	–8	1.33 ± .03	–14	1.21 ± .02	1.06 ± .02	
AB2, glass-fabric unsaturated-polyester	–70	53.8 ± 1.1	29	3.69 ± .05	11	3.69 ± .05	3.69 ± .05	
	77	41.7 ± .6		3.32 ± .02		3.31 ± .02	3.27 ± .02	1.5
	200	28.3 ± .5	–32	2.86 ± .05	–14	2.80 ± .04	2.74 ± .03	

[1] Lengthwise direction.
[2] Mean value for five to six specimens. The accompanying plus or minus value is the standard error S.E.
[3] Relative to 77° F values.
[4] At maximum load.

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TABLE IV.– PERCENTAGE CHANGES IN STRENGTH AND MODULUS OF ELASTICITY IN FLEXURAL,[1] TENSILE,[2] AND COMPRESSIVE[3] TESTS MADE AT –70° F AND 200° F BASED ON 77° F VALUES

Material designation	Strength						Modulus of elasticity					
	–70° F			200° F			–70° F			200° F		
	Flexural	Tensile	Compressive	Flexural	Tensile	Compressive	Flexural (4)	Tensile (5)	Compressive (6)	Flexural (4)	Tensile (5)	Compressive (6)
L, low-pressure cotton-fabric phenolic	22	15	54	–29	–25	–7	70	38	58	–7	–23	–23
V, low-pressure grade C phenolic	23	24	50	–30	–31	–11	51	47	62	–16	–18	–22
W, high-pressure grade C phenolic	28	20	53	–28	–30	–16	45	44	44	–20	–30	–24
I, high-pressure grade C phenolic	14	--	70	–34	---	–30	43	--	32	–21	---	–30
Z, rayon-cotton-fabric phenolic	28	26	86	–26	–26	–10	41	62	46	–30	–32	–28
S, high-strength-paper phenolic	26	16	84	–40	–42	–22	22	23	22	–18	–14	–17
K, asbestos-fabric phenolic	23	14	29	–5	–3	–8	38	23	16	0	–9	–14
AB, glass-fabric unsaturated-polyester	33	33	29	–35	–21	–32	14	23	11	–13	–21	–14

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[1]Percentage changes in flexural tests are average values from NACA TN No. 1054. Values are averages for the four combinations of lengthwise and crosswise specimens, flatwise and edgewise testing.
[2]Percentage changes in tensile tests are averages of the lengthwise and crosswise values given in table II of this report.
[3]Percentage changes in compressive tests are the values for the lengthwise direction given in table III of this report.
[4]Initial value.
[5]Secant value for lowest stress range, table II.
[6]Secant value for 0 to 2500 lb/sq in.

TABLE V.– DIRECTIONAL PROPERTIES OF LAMINATED PLASTICS AT 77° F

Material designation	Orientation of specimen	Tensile strength: Mean (10^3 lb/sq in.) [a]	Tensile strength: Percent of lengthwise value	Tensile secant modulus of elasticity: Mean (10^6 lb/sq in.) [a]	Tensile secant modulus of elasticity: Percent of lengthwise value	Tensile secant modulus of elasticity: Total strain (percent) [b]	Compressive strength: Mean (10^3 lb/sq in.) [a]	Compressive strength: Percent of lengthwise value	Compressive secant modulus of elasticity: Mean (10^6 lb/sq in.) [a]	Compressive secant modulus of elasticity: Percent of lengthwise values	Compressive secant modulus of elasticity: Total strain (percent) [c]
				0 to 2500 lb/sq in.							
L, low-pressure cotton-fabric phenolic, cross ply	Lengthwise	11.7 ± 0.3	100	0.96 ± 0.01	100	4.9	22.0 ± 0.1	100	0.93 ± 0.01	100	12.2
	Crosswise	11.2 ± .2	95	1.05 ± .04	110	4.8	22.2 ± .1	101	.90 ± .01	97	11.6
	45° diagonal	9.4 ± .3	85	.83 ± .01	79	8.7	----------	---	----------	---	----
V, low-pressure grade C phenolic, cross ply	Lengthwise	8.9 ± .1	100	.84 ± .02	100	4.8	19.4 ± .5	100	.86 ± .01	100	10.5
	Crosswise	8.8 ± .1	99	.81 ± .01	96	5.0	----------	---	----------	---	----
	45° diagonal	8.0 ± .1	90	.68 ± .01	81	8.5	19.4 ± .3	100	.76 ± .01	88	14.7
W, high-pressure grade C phenolic, cross ply	Lengthwise	10.3 ± .1	100	1.05 ± .03	100	3.7	20.4 ± .2	100	1.07 ± .01	100	8.6
	Crosswise	10.3 ± .3	100	1.05 ± .01	100	4.8	20.1 ± .3	99	1.08 ± .02	101	8.2
	45° diagonal	9.2 ± .1	89	.99 ± .01	94	4.7	19.9 ± .1	98	.85 ± .01	79	11.8
I, grade C phenolic, parallel ply	Lengthwise						24.7 ± .1	100	1.27 ± .02	100	12.0
	Crosswise						22.7 ± .2	92	1.27 ± .03	100	----
				0 to 5000 lb/sq in.							
Z, rayon-cotton fabric phenolic, cross ply	Lengthwise	32.4 ± .1	100	1.87 ± .02	100	4.0	[d]24.8 ± .1	100	[d]2.03 ± .01	100	5.7
	Crosswise	25.5 ± .3	79	1.58 ± .02	84	3.9	[d]23.7 ± .8	96	[d]1.89 ± .02	93	5.8
	45° diagonal	10.0 ± .1	32	.82 ± .01	44	4.9	[d]22.7 ± .1	92	[d]1.10 ± .01	54	8.6
S, high-strength-paper phenolic, cross ply	Lengthwise	29.7 ± .5	100	2.61 ± .02	100	1.7	19.2 ± .1	100	2.68 ± .02	100	4.5
	Crosswise	30.8 ± .2	104	2.59 ± .02	99	1.7	19.1 ± .1	100	2.73 ± .02	102	----
	45° diagonal	29.6 ± .3	100	2.40 ± .02	92	2.0	----------	---	----------	---	----
				0 to 2500 lb/sq in.							
K, asbestos-fabric phenolic, parallel ply	Lengthwise	8.2 ± .2	100	1.48 ± .05	100	1.8	19.9 ± .2	100	1.55 ± .05	100	5.1
	Crosswise	5.0 ± .2	61	1.15 ± .02	78	.6	21.8 ± .2	110	1.16 ± .03	75	6.3
	45° diagonal	6.2 ± .1	76	1.15 ± .02	78	.6	21.3 ± .1	107	1.42 ± .01	92	5.4
				0 to 5000 lb/sq in.							
AB, glass-fabric unsaturated-polyester, parallel ply	Lengthwise	42.9 ± 1.0	100	3.03 ± .07	100	1.8	41.7 ± .6	100	3.32 ± .02	100	1.5
	Crosswise	33.3 ± 1.5	78	2.63 ± .15	87	1.7	36.2 ± 1.0	87	3.14 ± .03	95	1.5
	45° diagonal	22.3 ± .4	52	1.34 ± .03	44	8.2	24.3 ± .6	58	2.47 ± .08	74	2.5

[a] Mean value for five to ten specimens. The accompanying plus or minus value is the standard error S.E.

[b] At failure.

[c] At maximum load.

[d] This sample received later than the $\frac{1}{8}$-inch material tested in tension and the $\frac{1}{2}$-inch material tested in flexure (see table I). Tests on the earlier $\frac{1}{2}$-inch sample and on a duplicate sheet used by Marin (reference 8) yielded compressive strengths of 20.2 and 20.1 × 10^3 lb/sq in. and secant moduli (0 to 2500 lb/sq in.) of 1.96 and 1.94 × 10^6 lb/sq in., respectively, for lengthwise specimens.

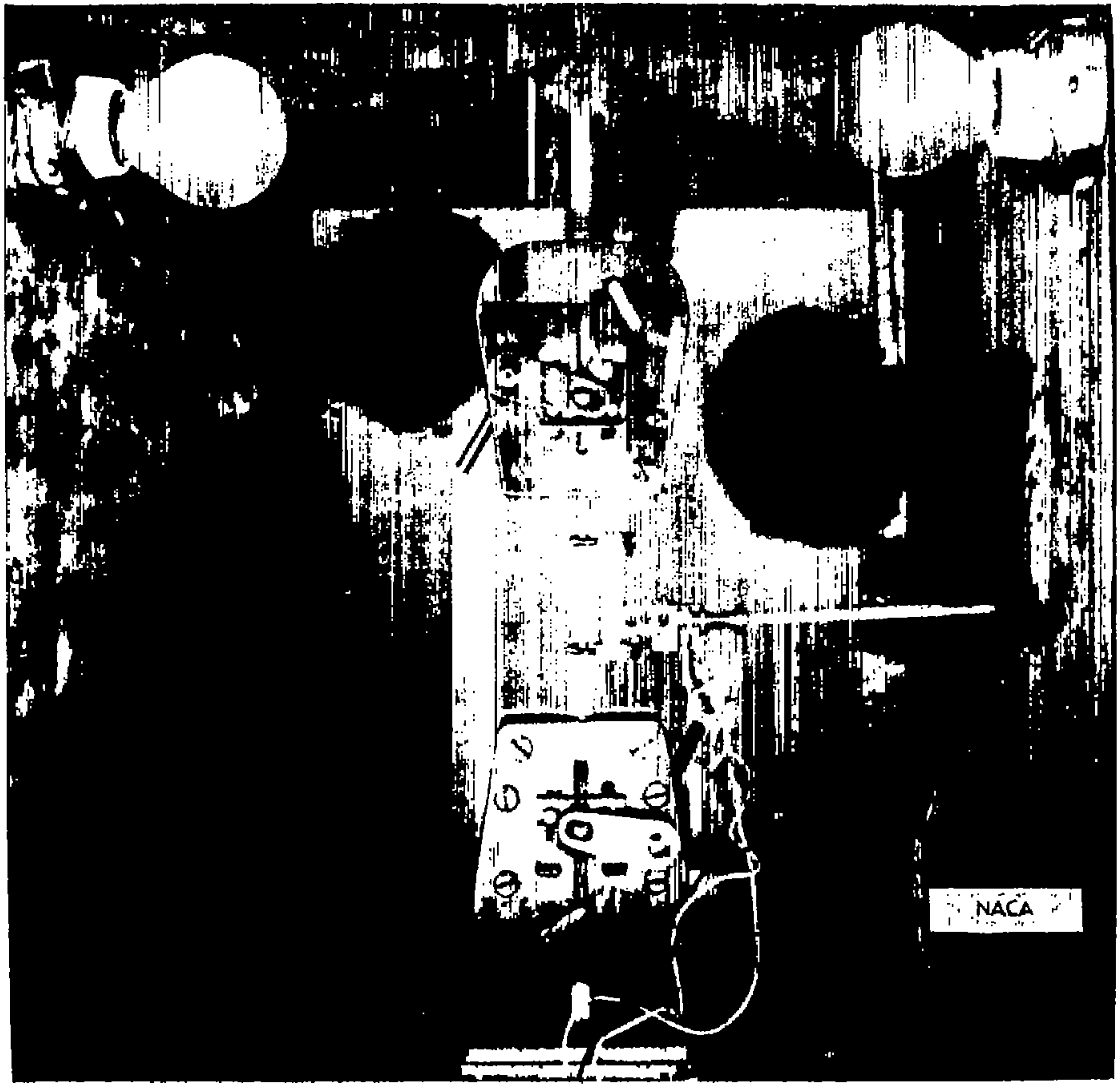


Figure 1.- Interior view of tensile test enclosure with specimen in grips and extensometer attached.

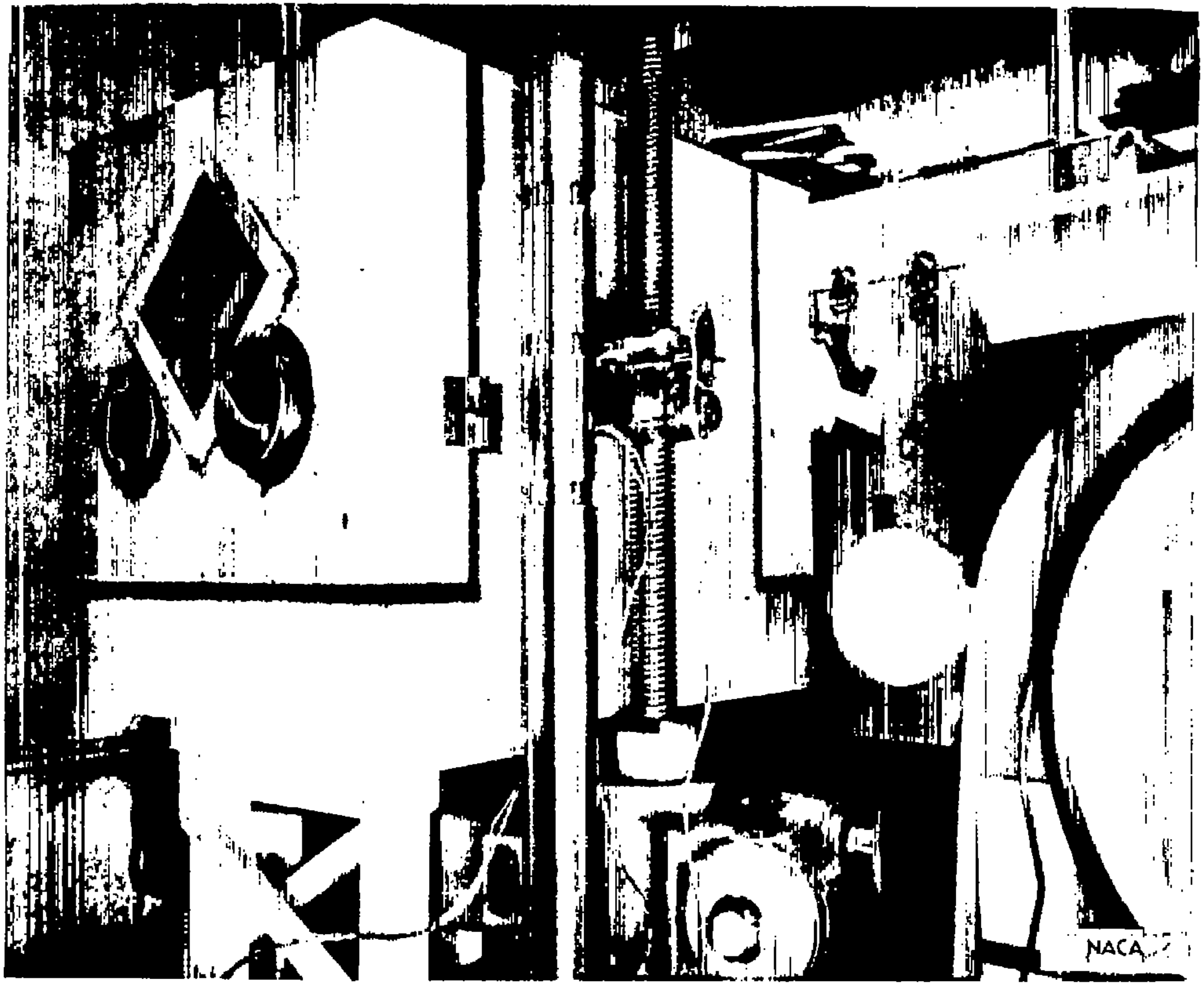


Figure 2.- Front view of tensile test enclosure in place in testing machine.

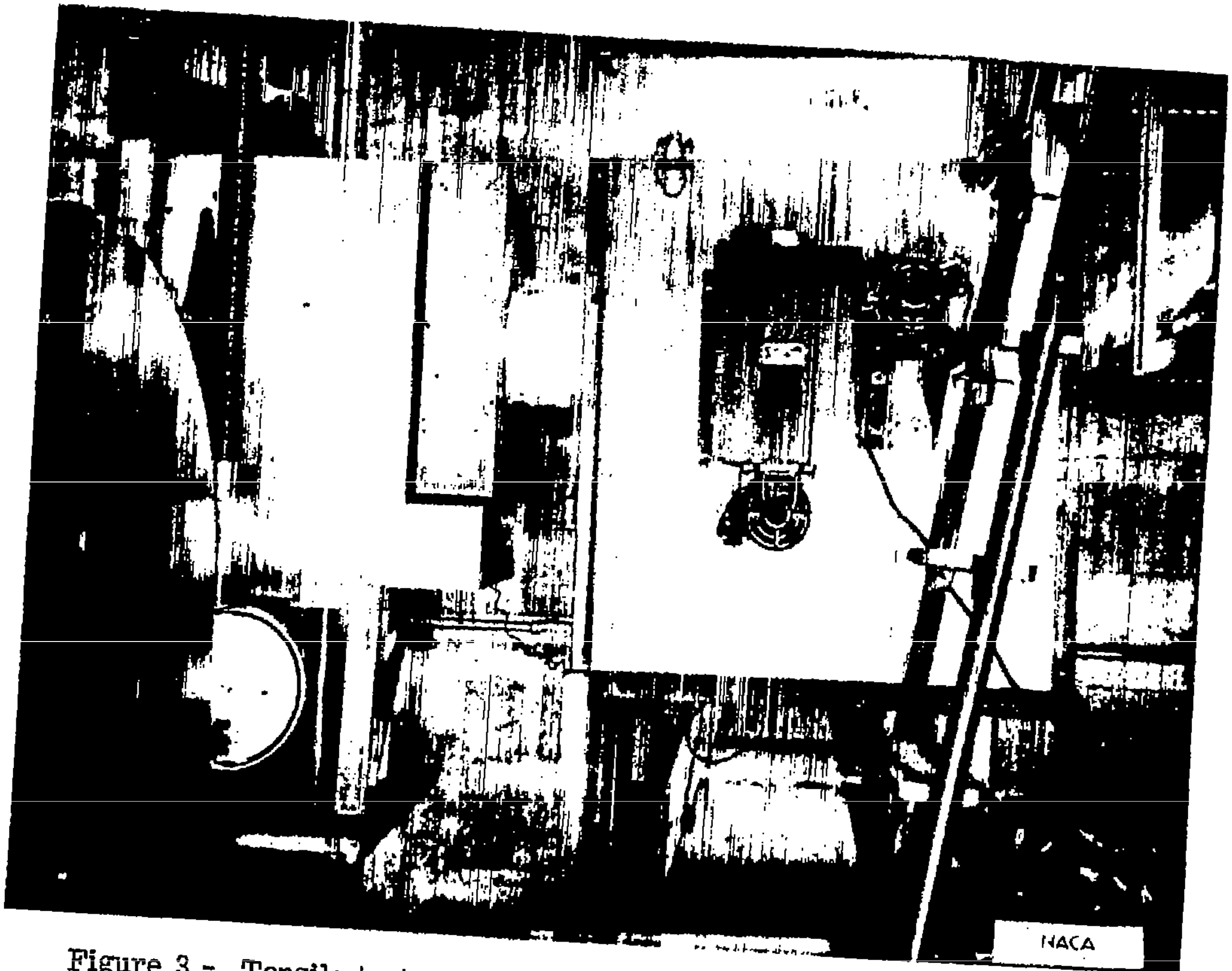


Figure 3. - Tensile test enclosure and conditioning unit ready for test.

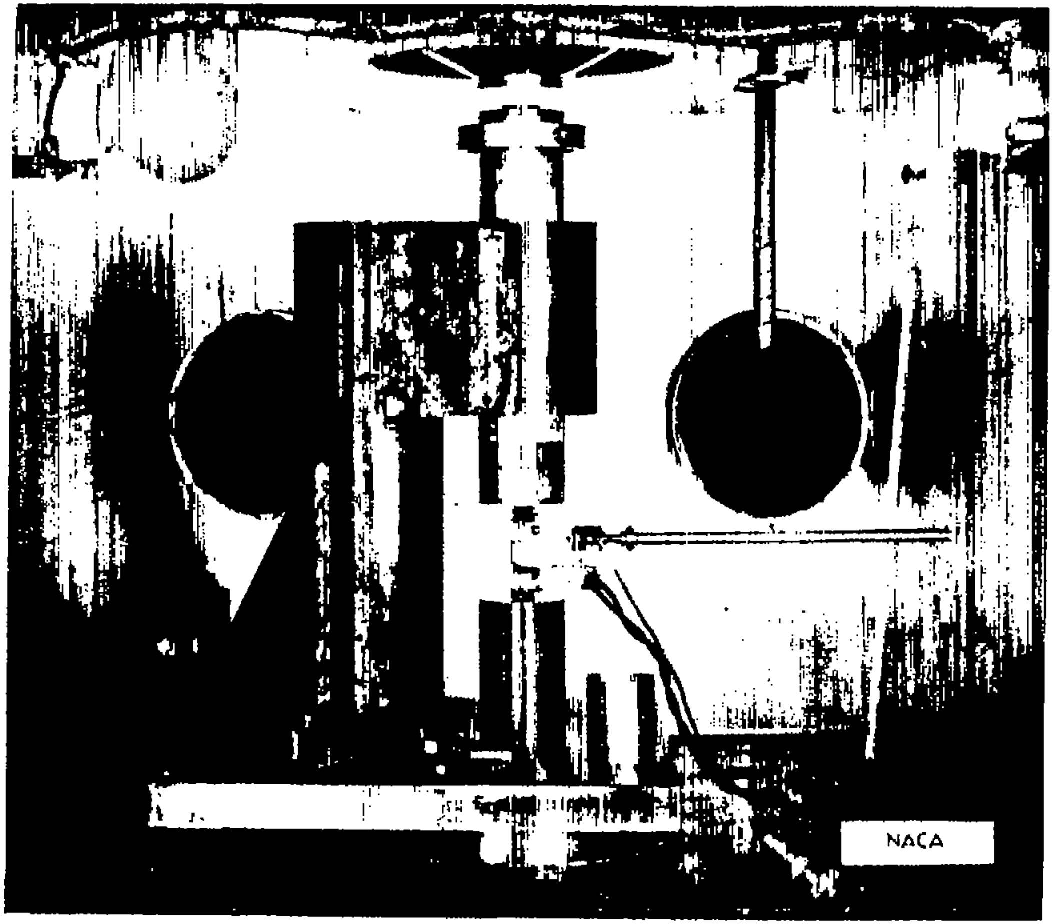


Figure 4.- Interior view of compression test enclosure with specimen in place in compression tool and extensometer attached.

Figure 5.- Compression tool in place with insulated support and loading blocks.

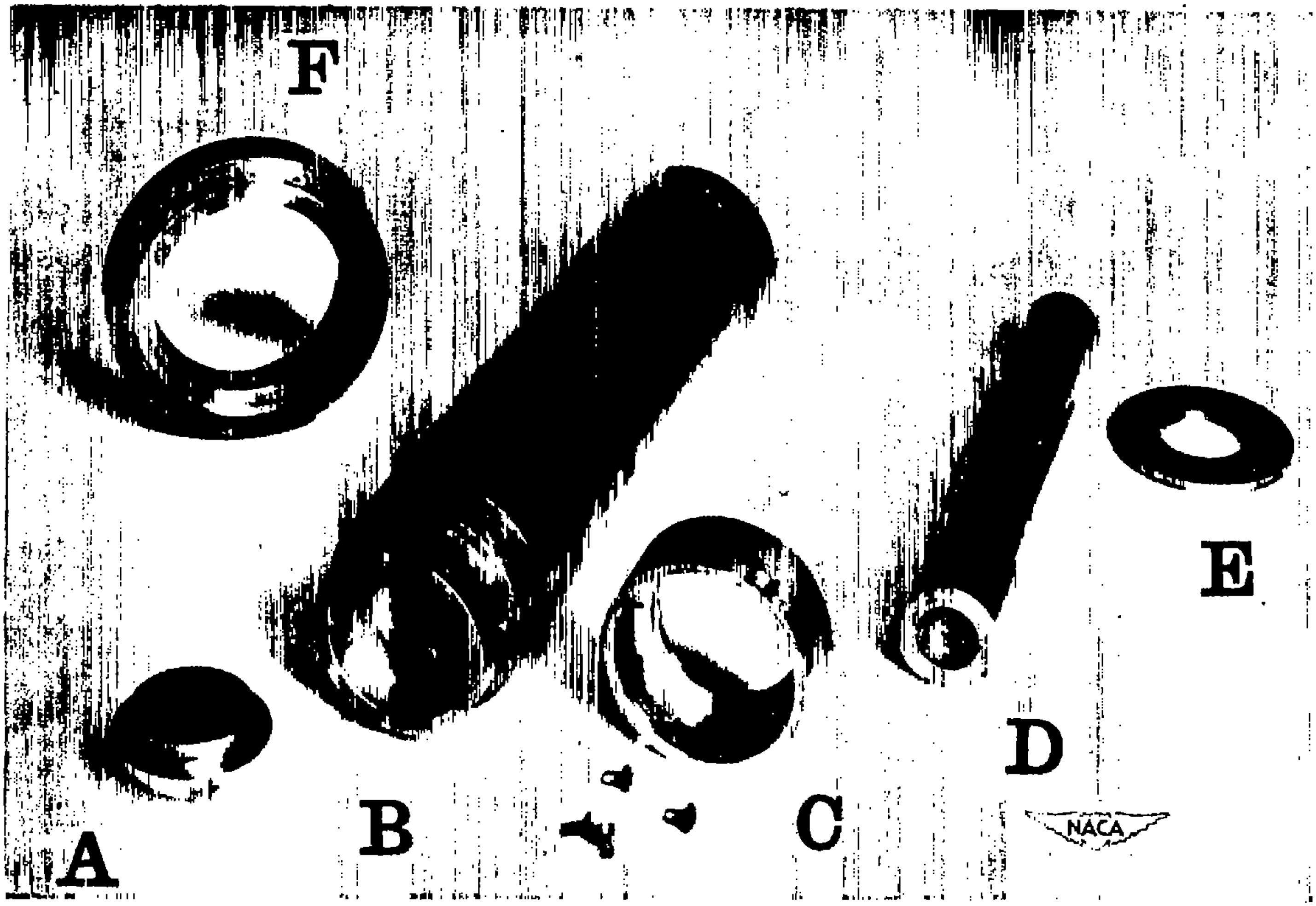


Figure 6.- Disassembled compression tool plunger. A, spherically seated bearing block; B, plunger (ball through which load is transmitted from rod D to plunger is inside latter); C, retainer for bearing block; D, loading rod; E, centering washer for rod D; F, limit collar for plunger.

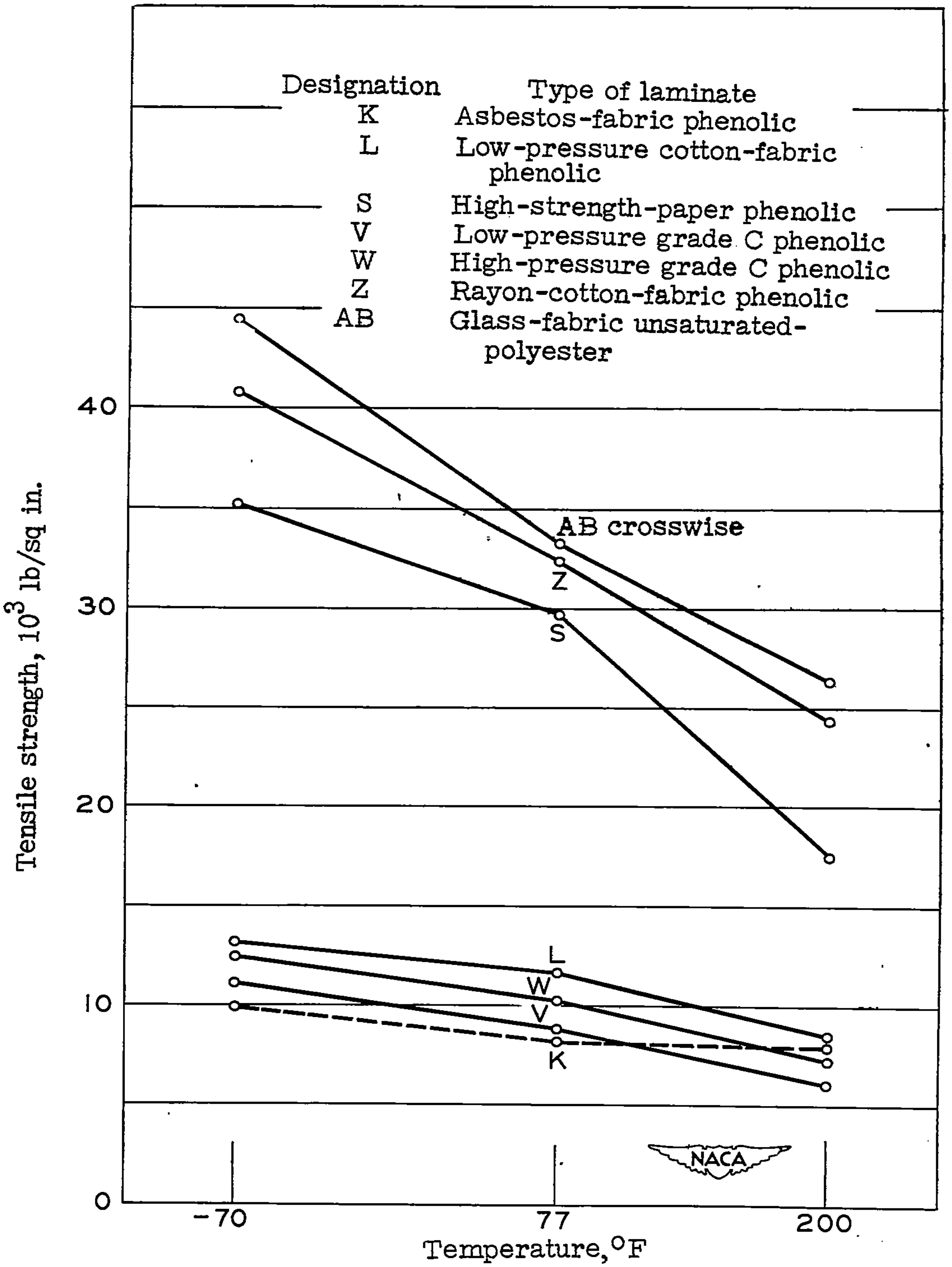


Figure 7.- Variation of tensile strength with temperature for $\frac{1}{8}$-inch-thick laminates. Lengthwise direction unless noted.

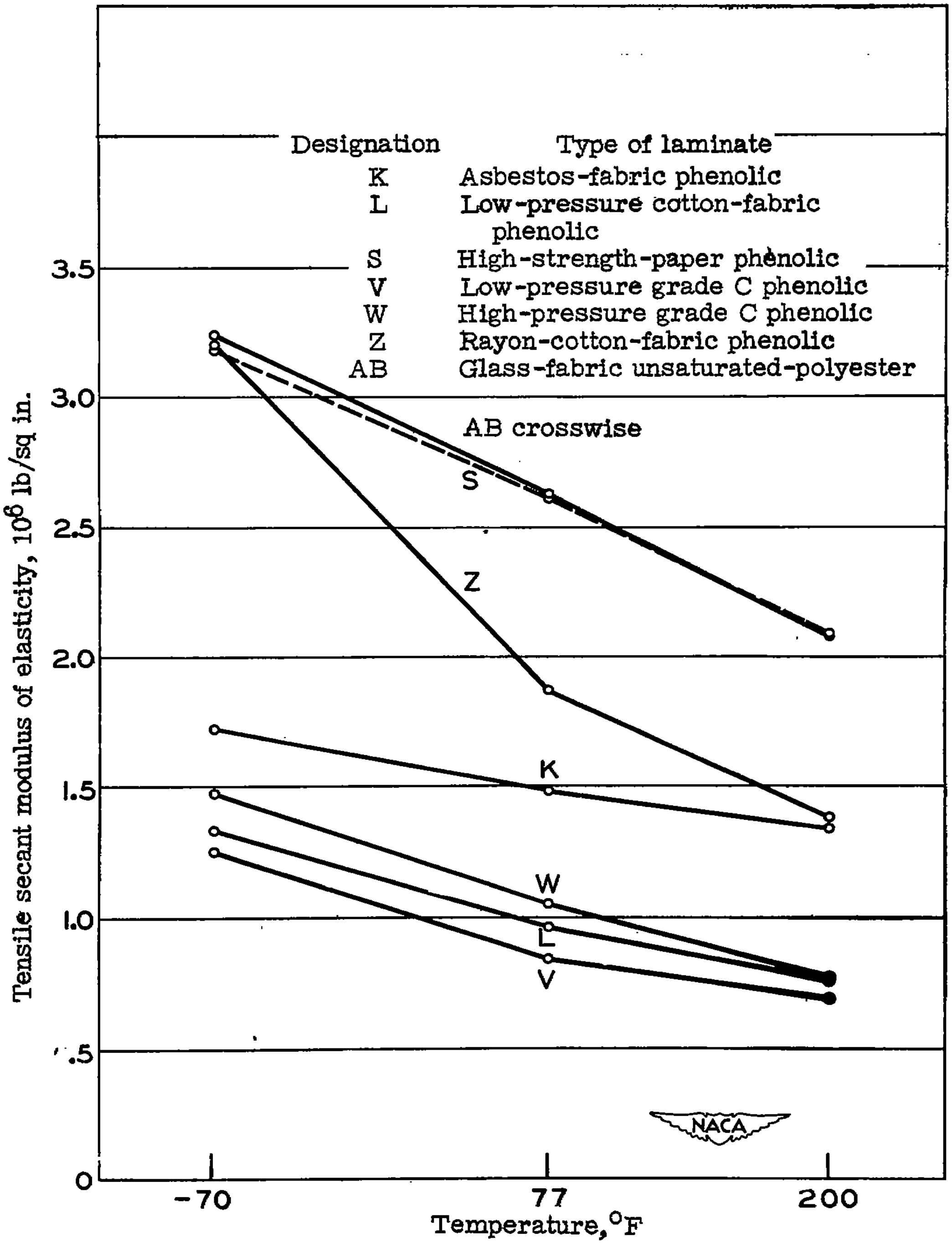


Figure 8.- Variation of tensile secant modulus of elasticity with temperature for $\frac{1}{8}$-inch-thick laminates. Lengthwise direction. Stress ranges: 0 to 5000 pounds per square inch for AB, S, and Z; 0 to 2500 pounds per square inch for K, W, L, and V.

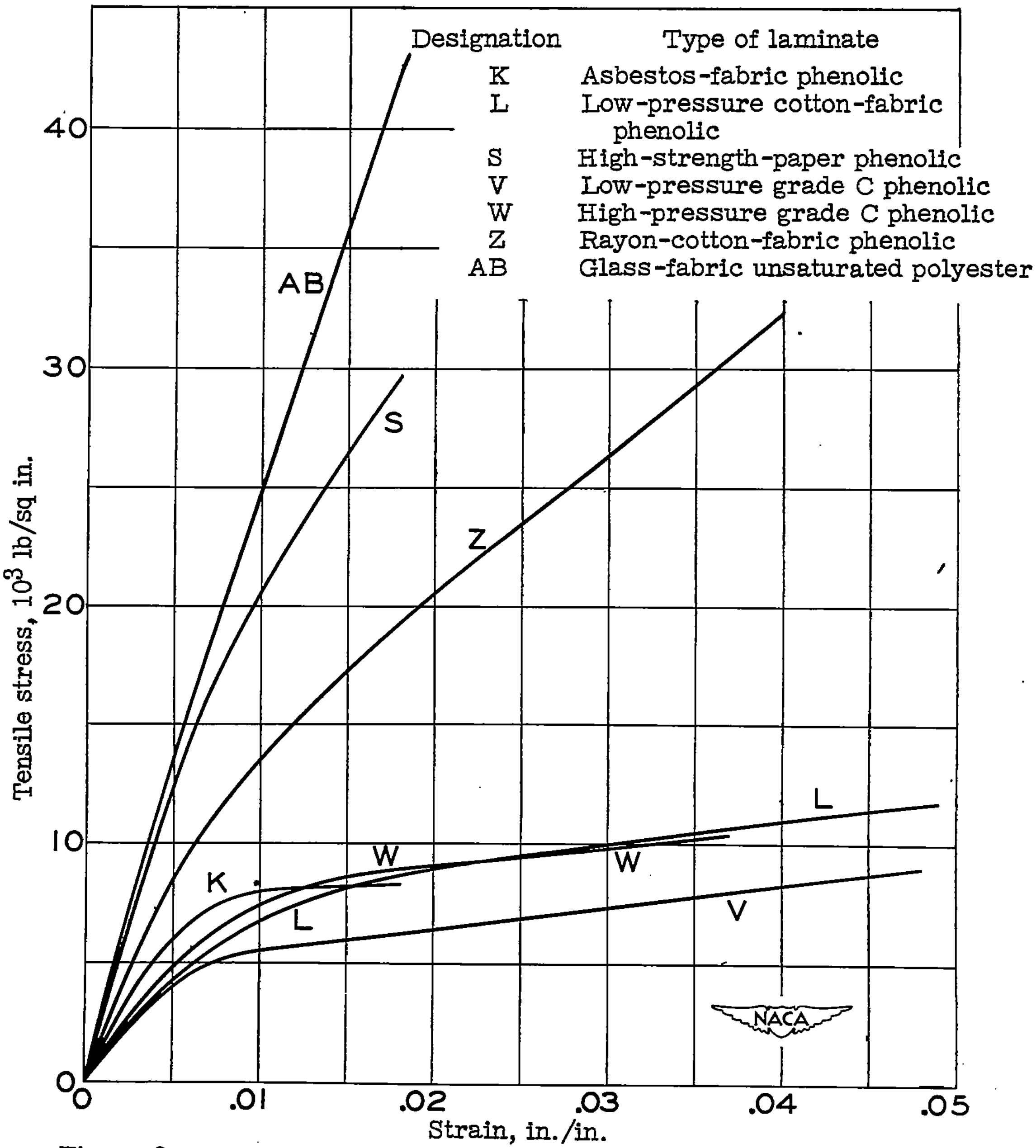


Figure 9.- Tensile stress-strain curves of plastic laminates at 77° F. Lengthwise direction.

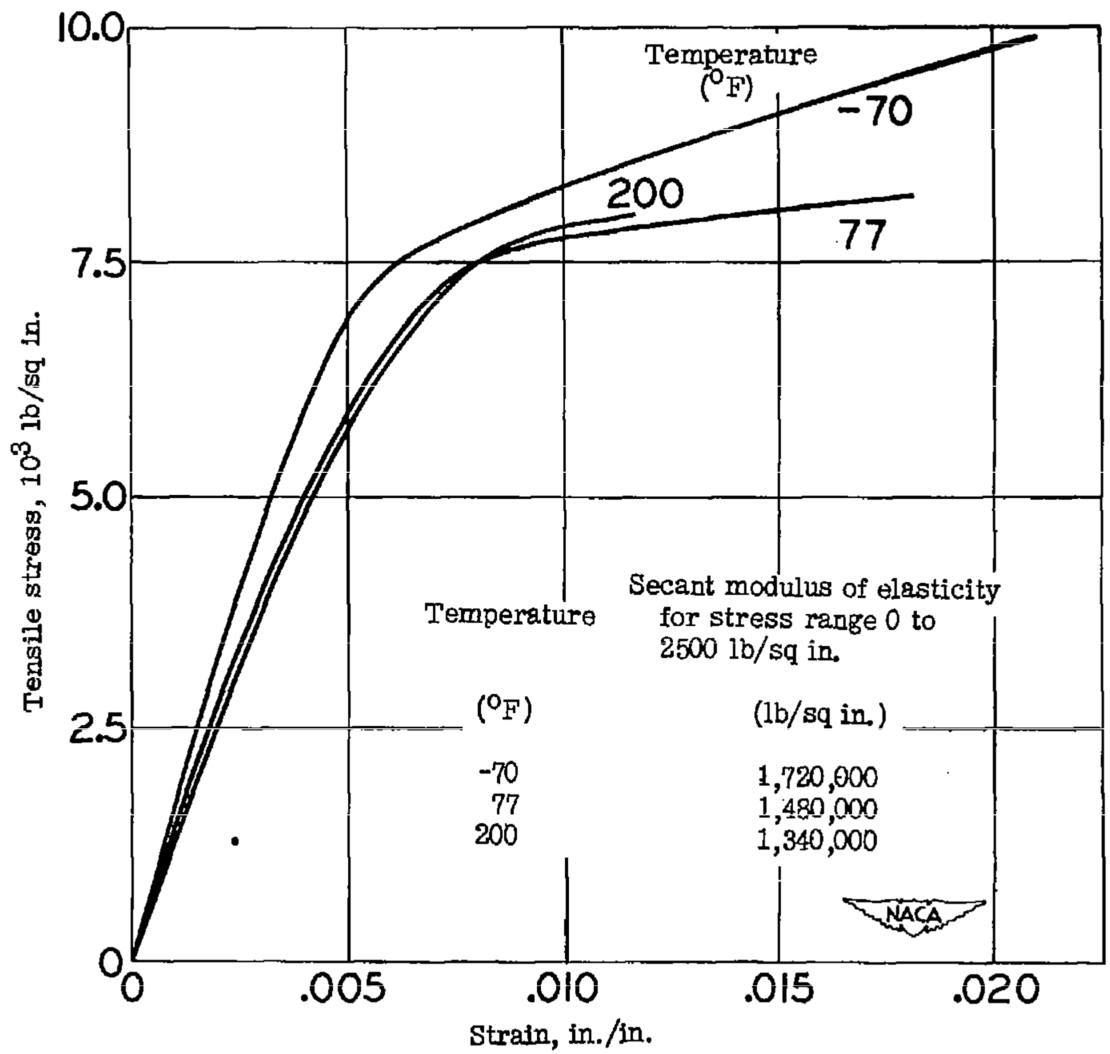


Figure 10.- Tensile stress-strain curves for grade AA asbestos-fabric phenolic laminate K1. Lengthwise specimens.

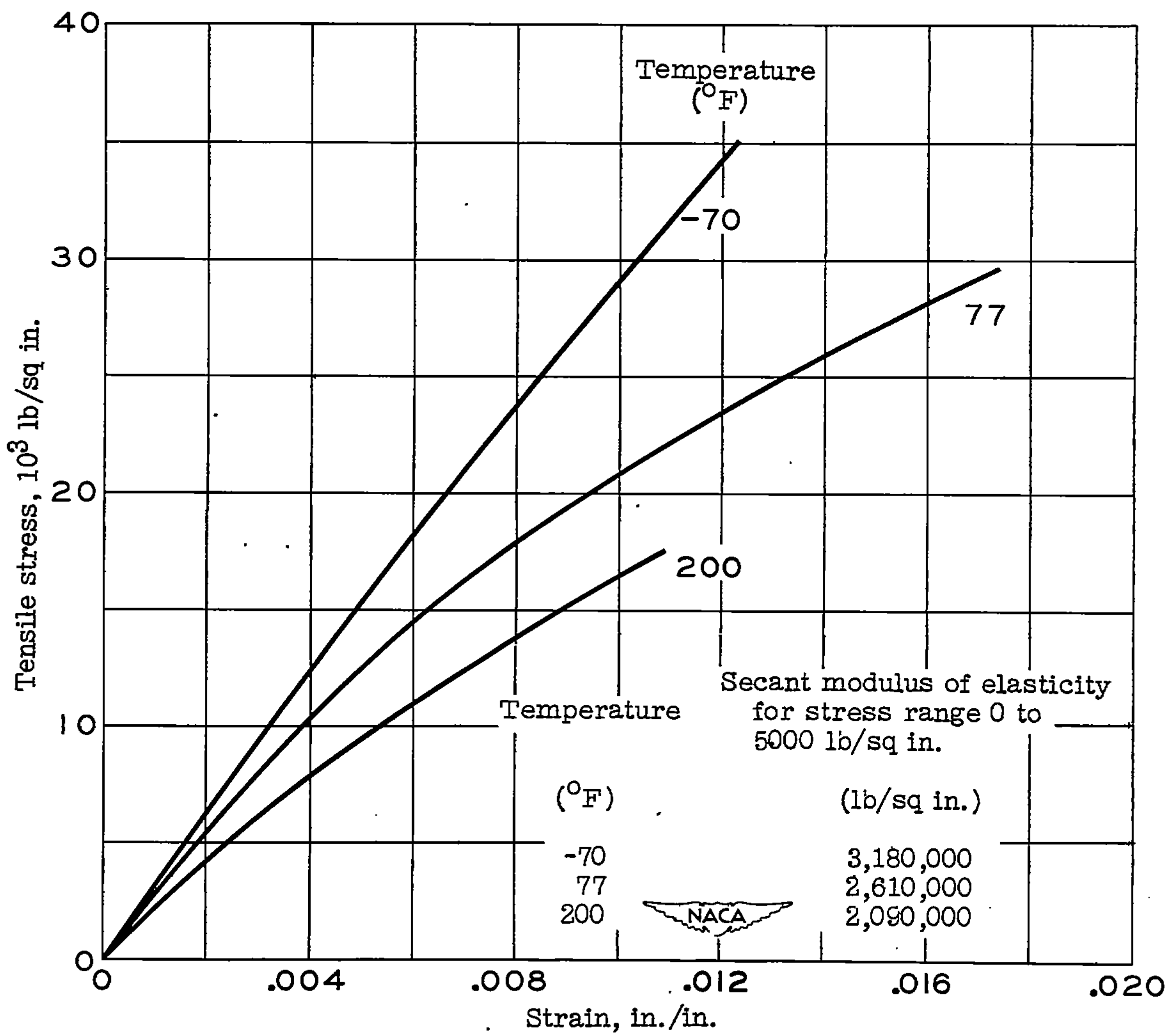


Figure 11.- Tensile stress-strain curves of high-strength-paper phenolic laminate S1. Lengthwise specimens.

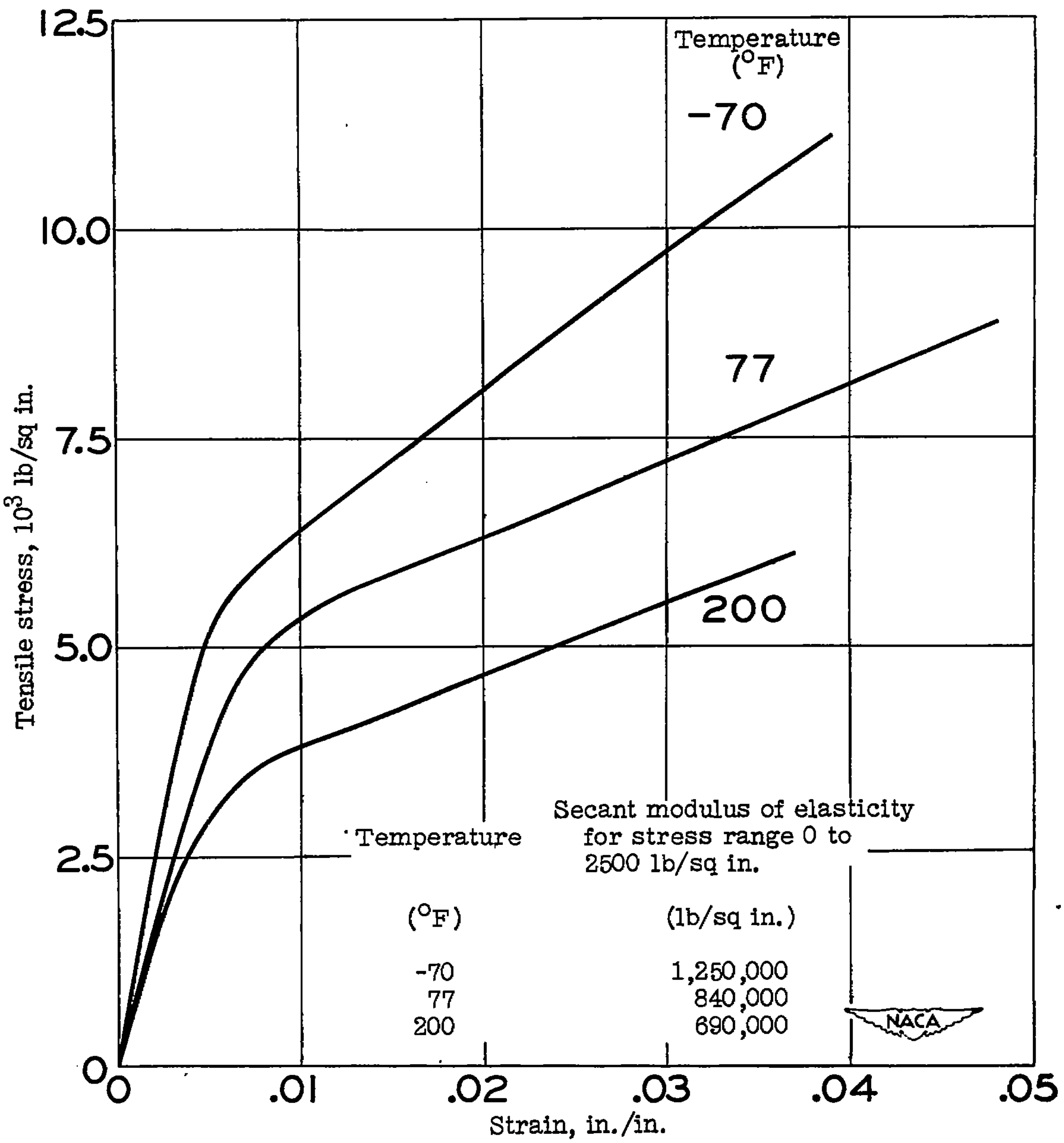


Figure 12.- Tensile stress-strain curves for low-pressure grade C phenolic laminate V1. Lengthwise specimens.

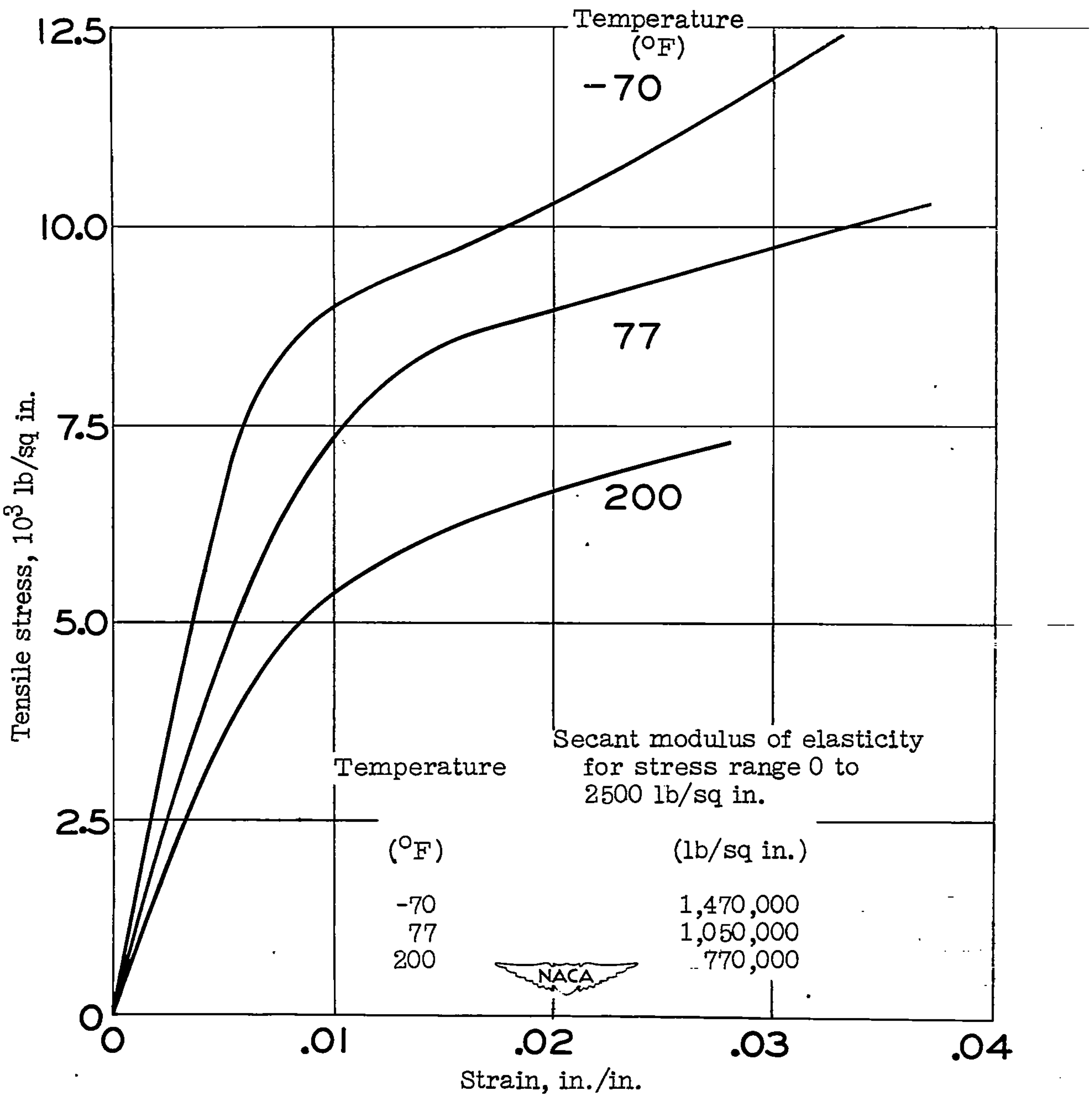


Figure 13.- Tensile stress-strain curves for high-pressure grade C phenolic laminate W1. Lengthwise specimens.

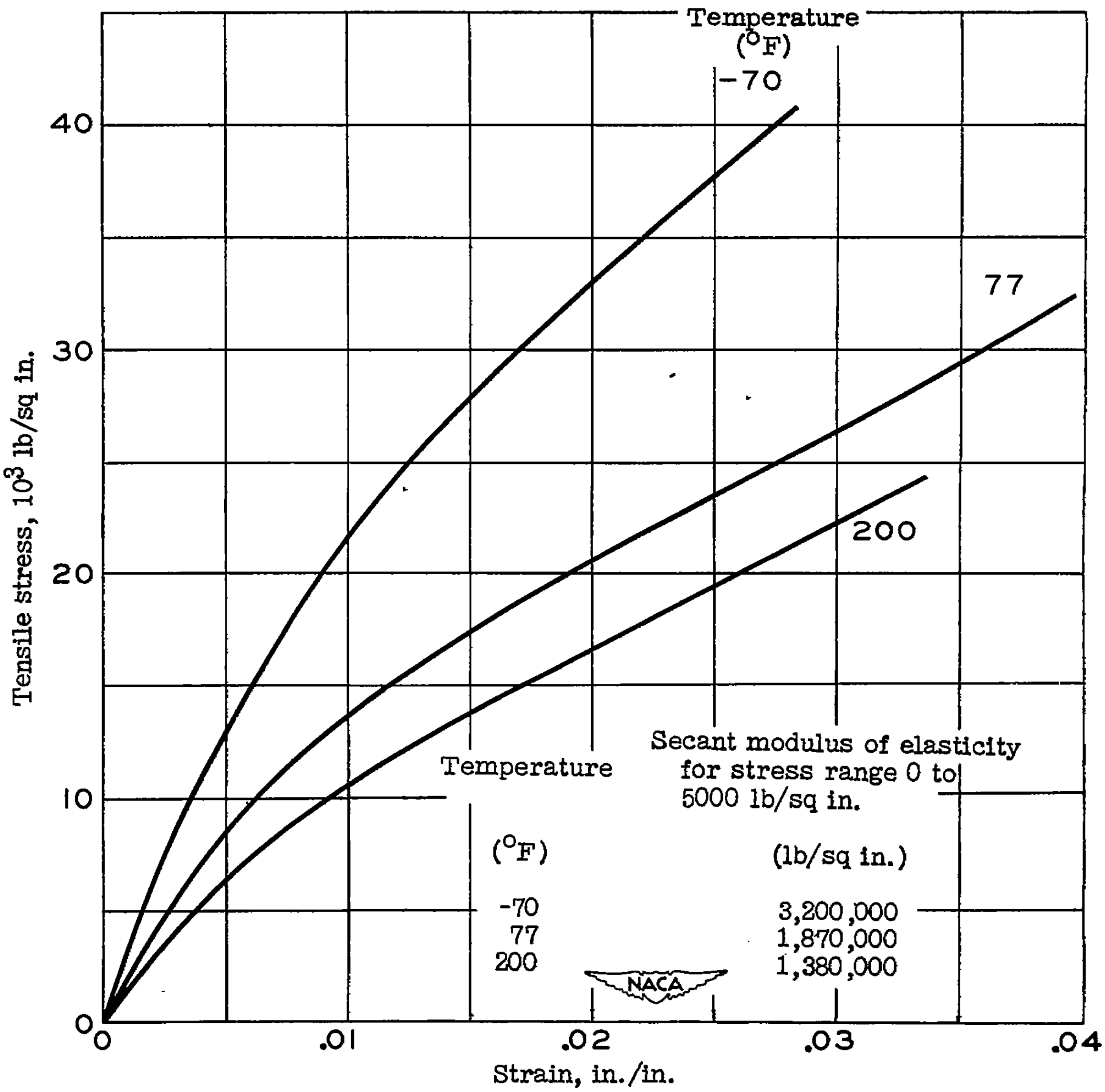


Figure 14.- Tensile stress-strain curves for rayon-cotton-fabric phenolic laminate Z1. Legnthwise specimens.

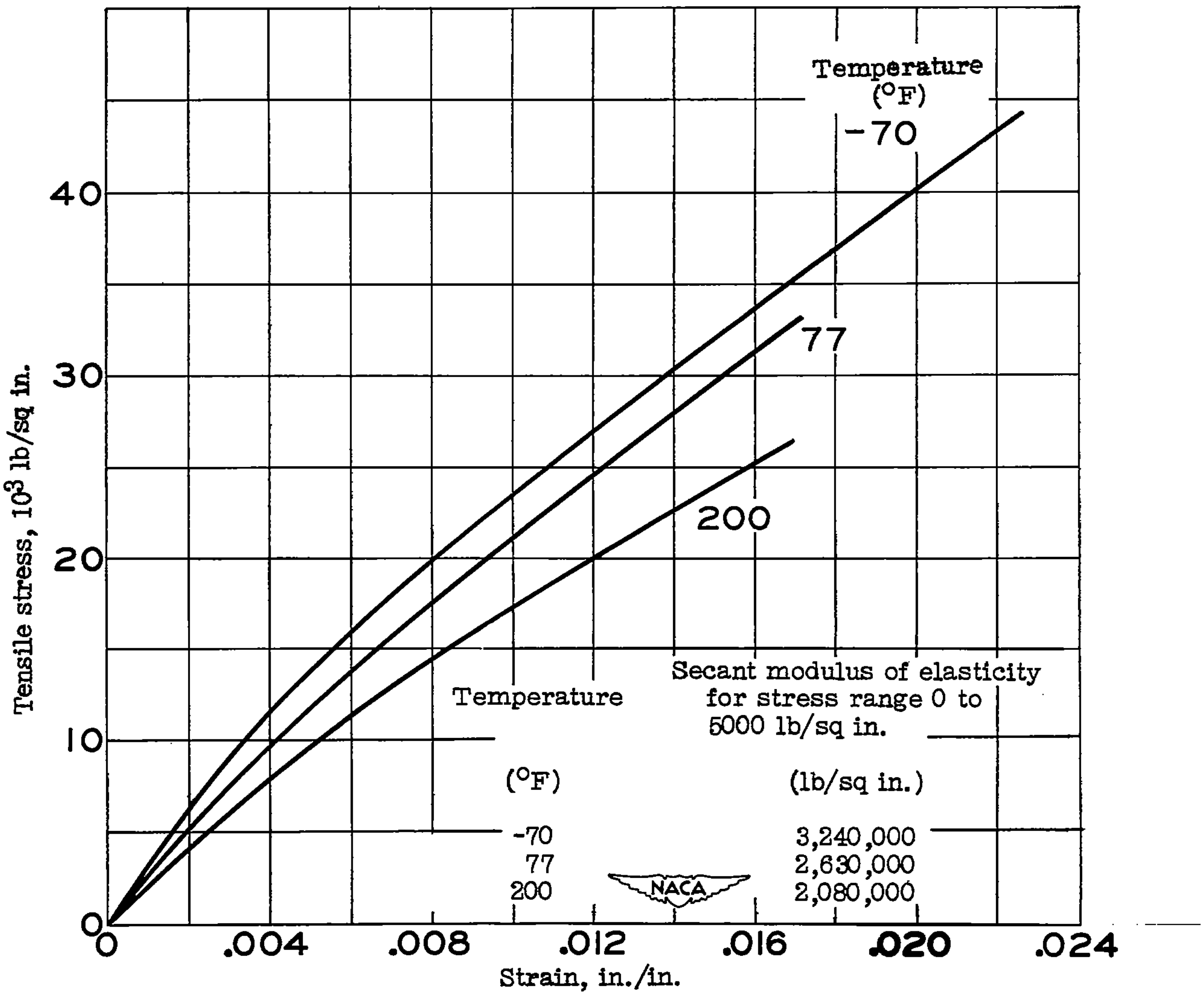


Figure 15.- Tensile stress-strain curves for glass-fabric unsaturated-polyester laminate AB1. Crosswise specimens.

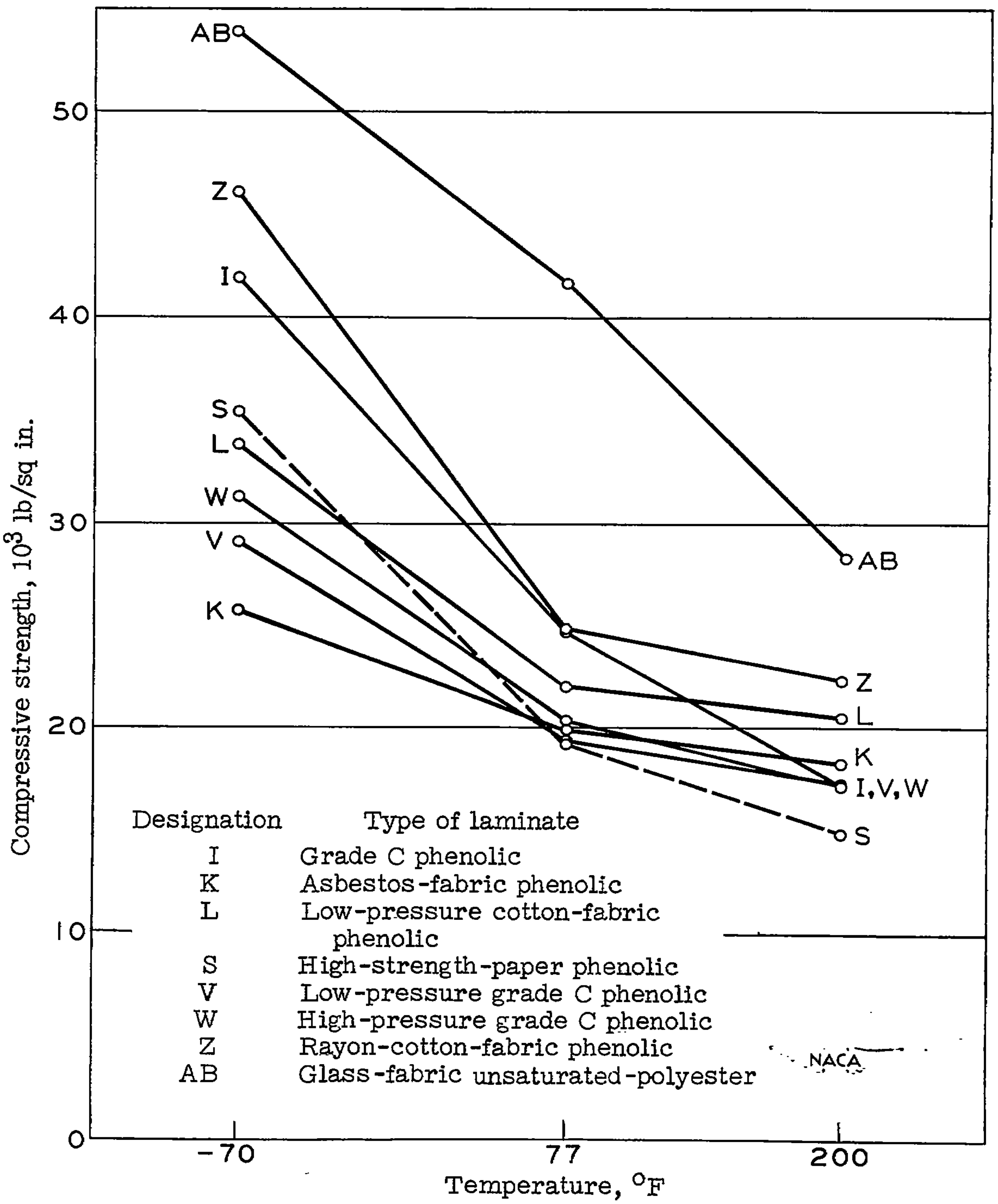


Figure 16.- Variation of compressive strength with temperature for $\frac{1}{2}$-inch-thick laminates.

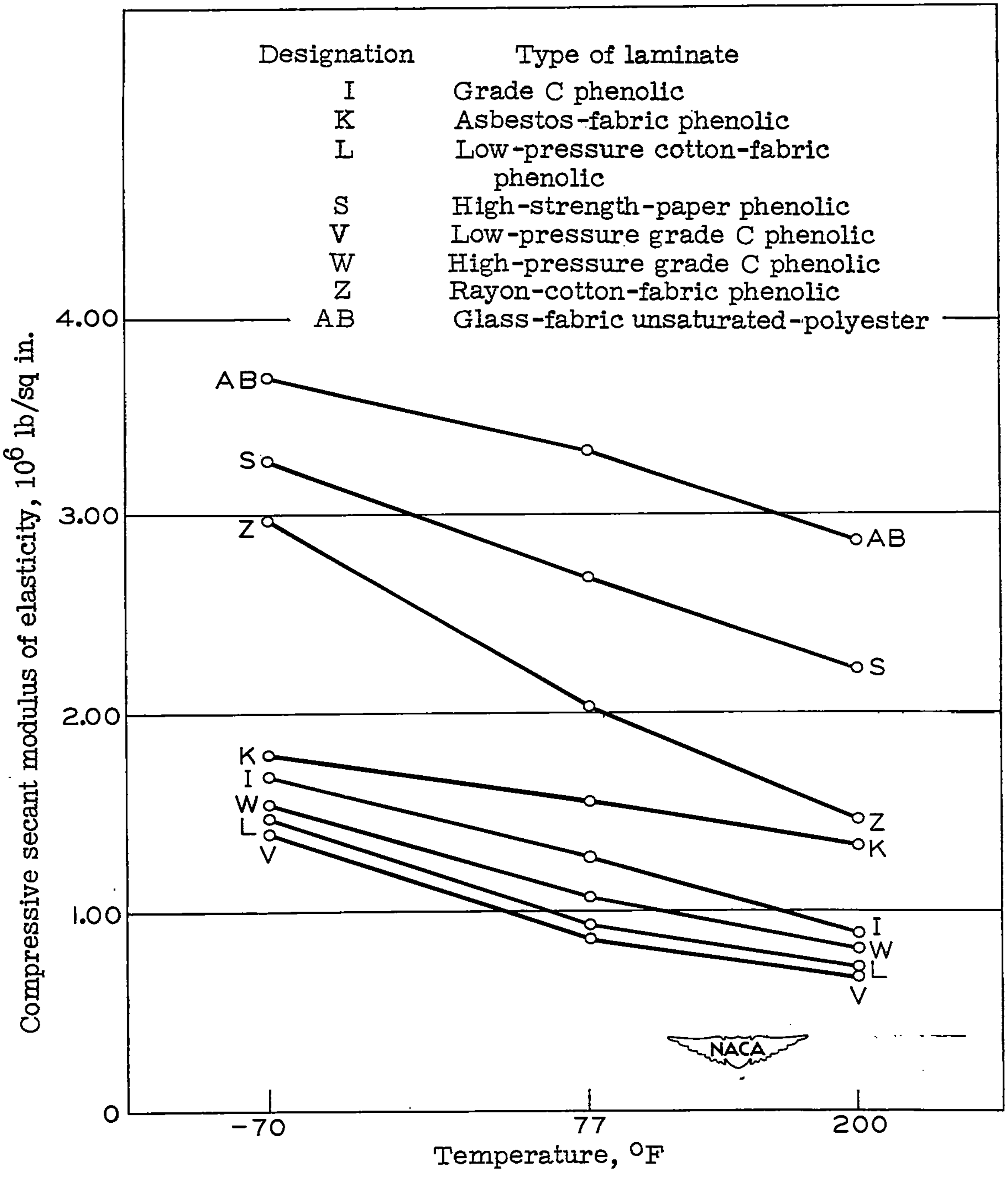


Figure 17.- Variation of compressive secant modulus of elasticity (0 to 2500 lb/sq in.) with temperature for $\frac{1}{2}$-inch-thick laminates.

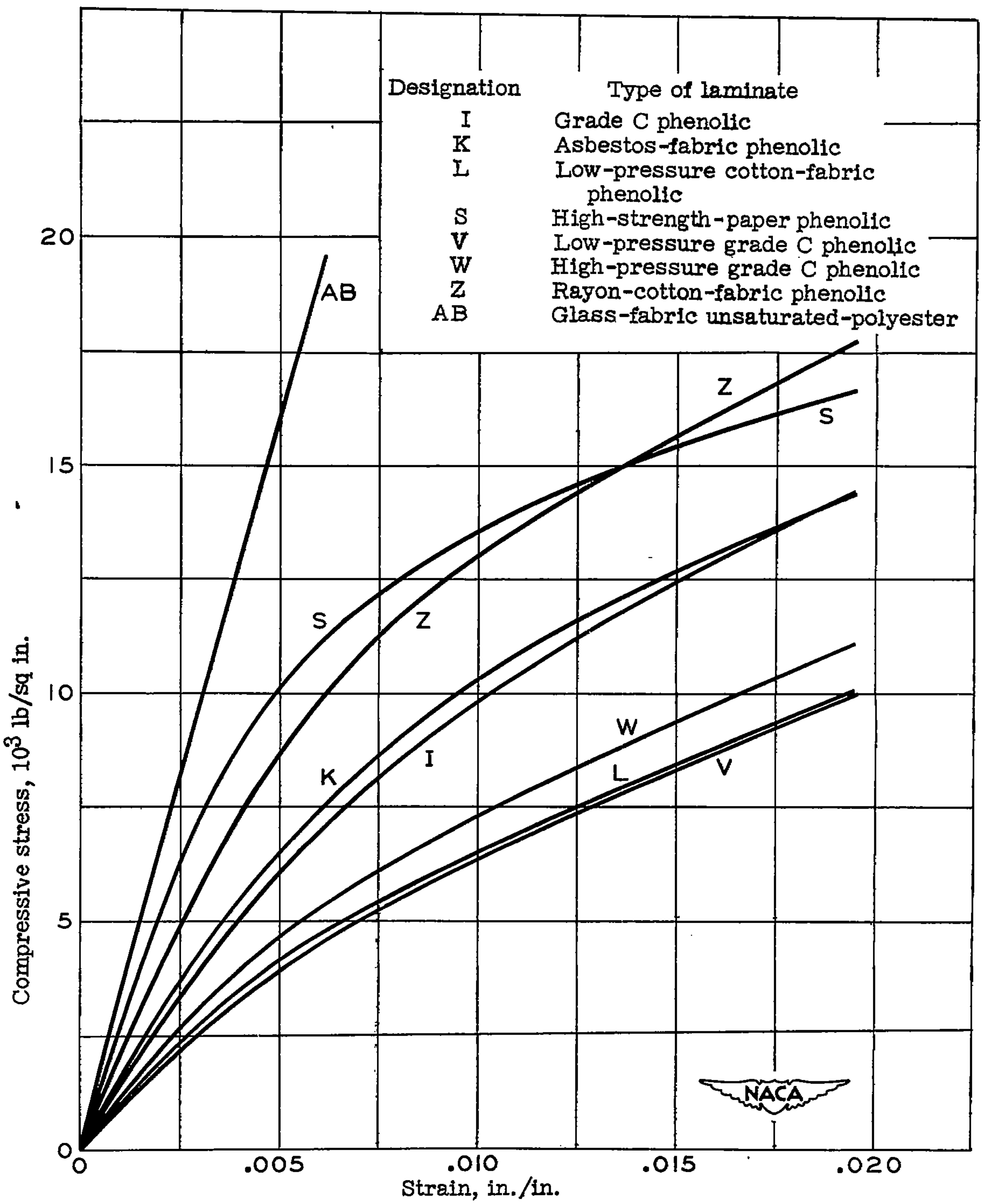


Figure 18.- Compressive stress-strain curves of plastic laminates at 77° F. Lengthwise direction.

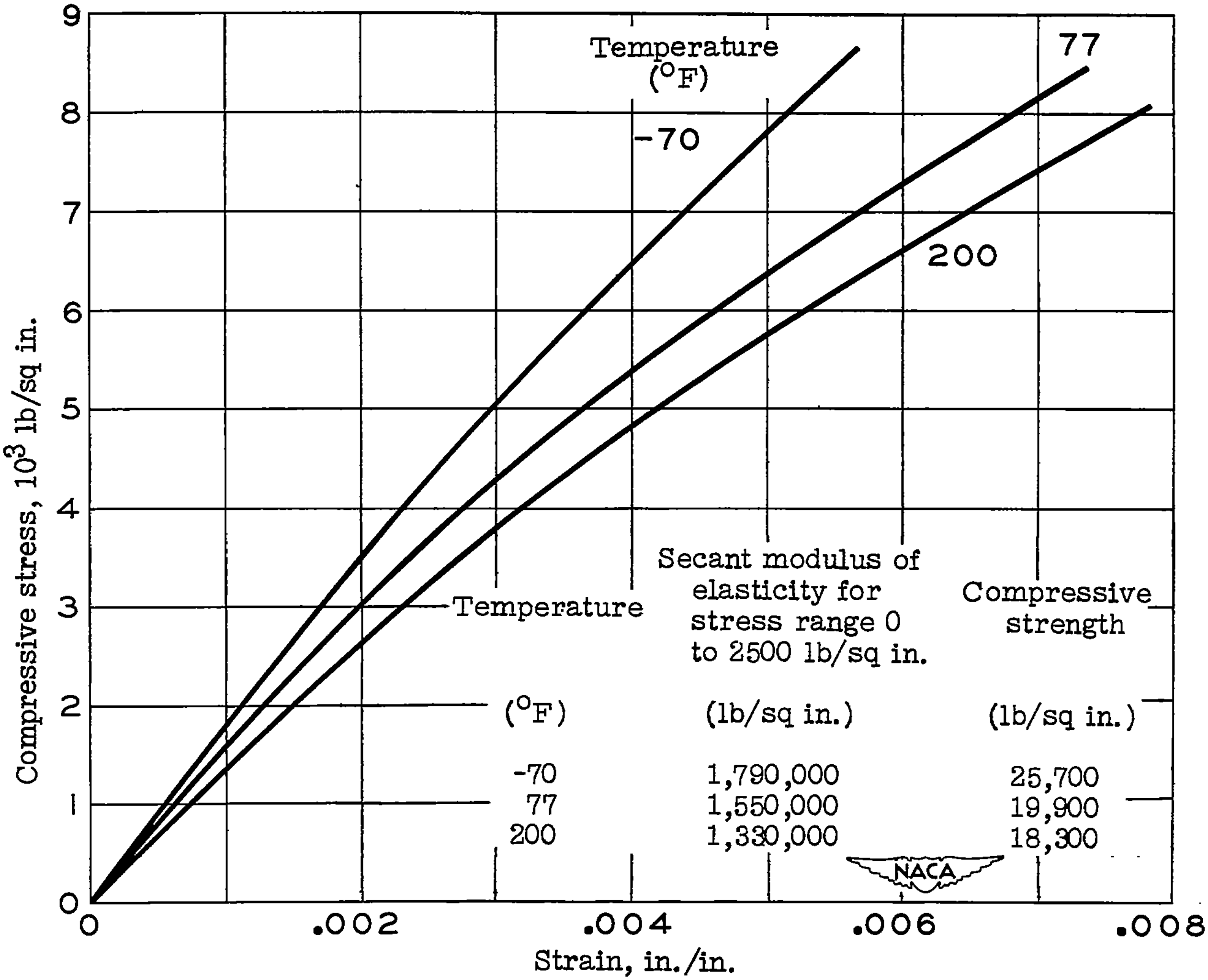


Figure 19.- Compressive stress-strain curves of grade AA asbestos-fabric phenolic laminate K2. Lengthwise specimens.

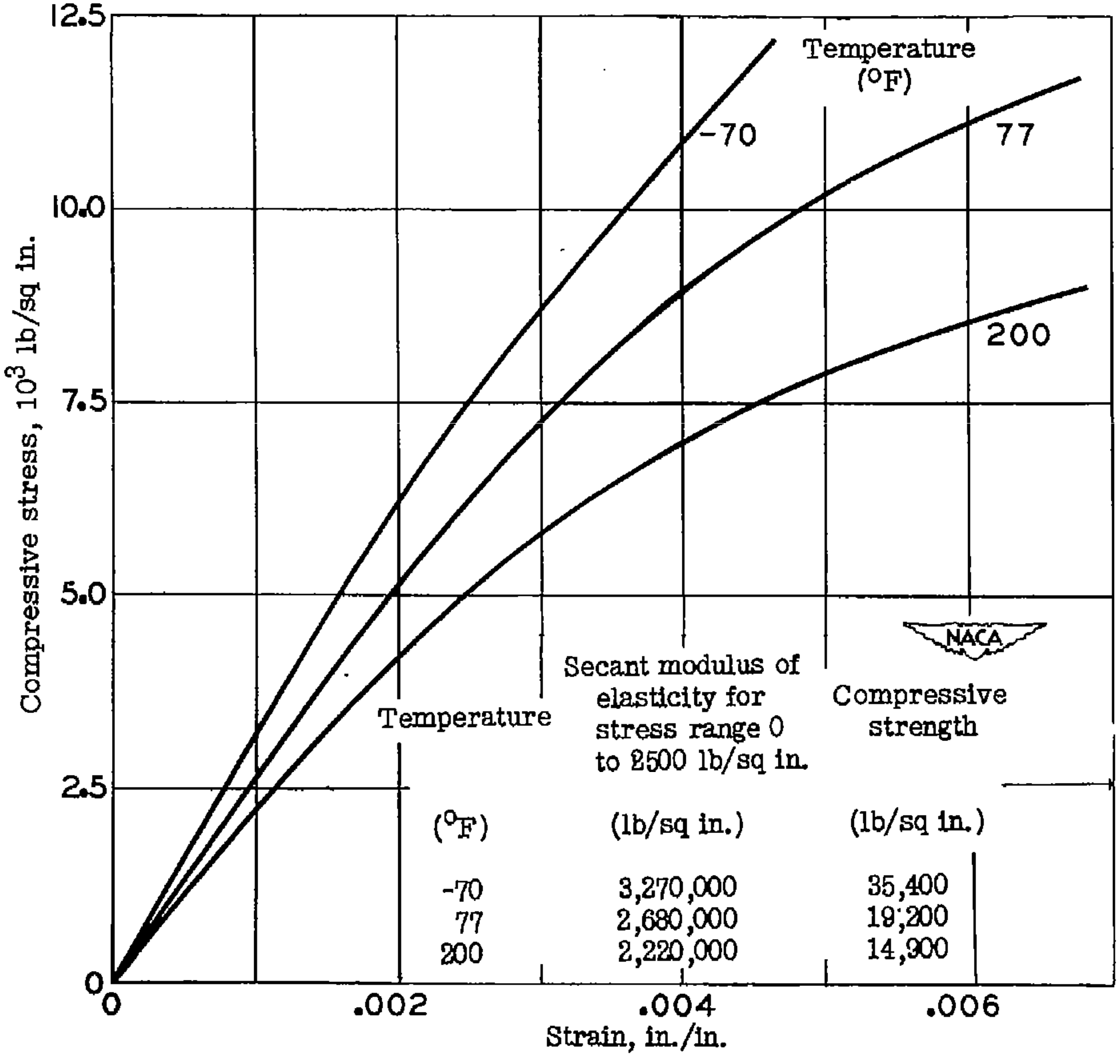


Figure 20.- Compressive stress-strain curves of high-strength-paper phenolic laminate S2. Lengthwise specimens.

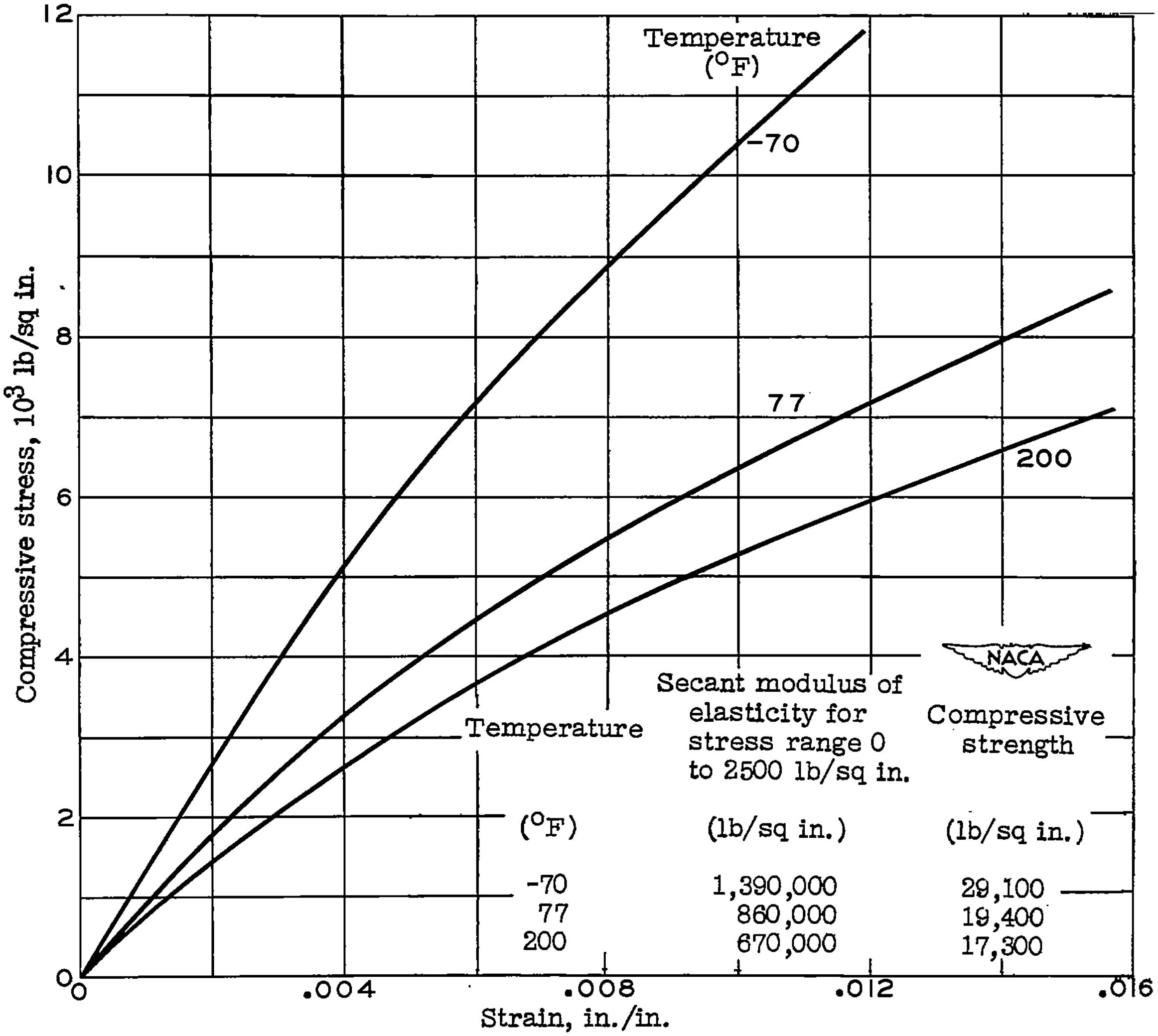


Figure 21.- Compressive stress-strain curves of low-pressure grade C phenolic laminate V2. Lengthwise specimens.

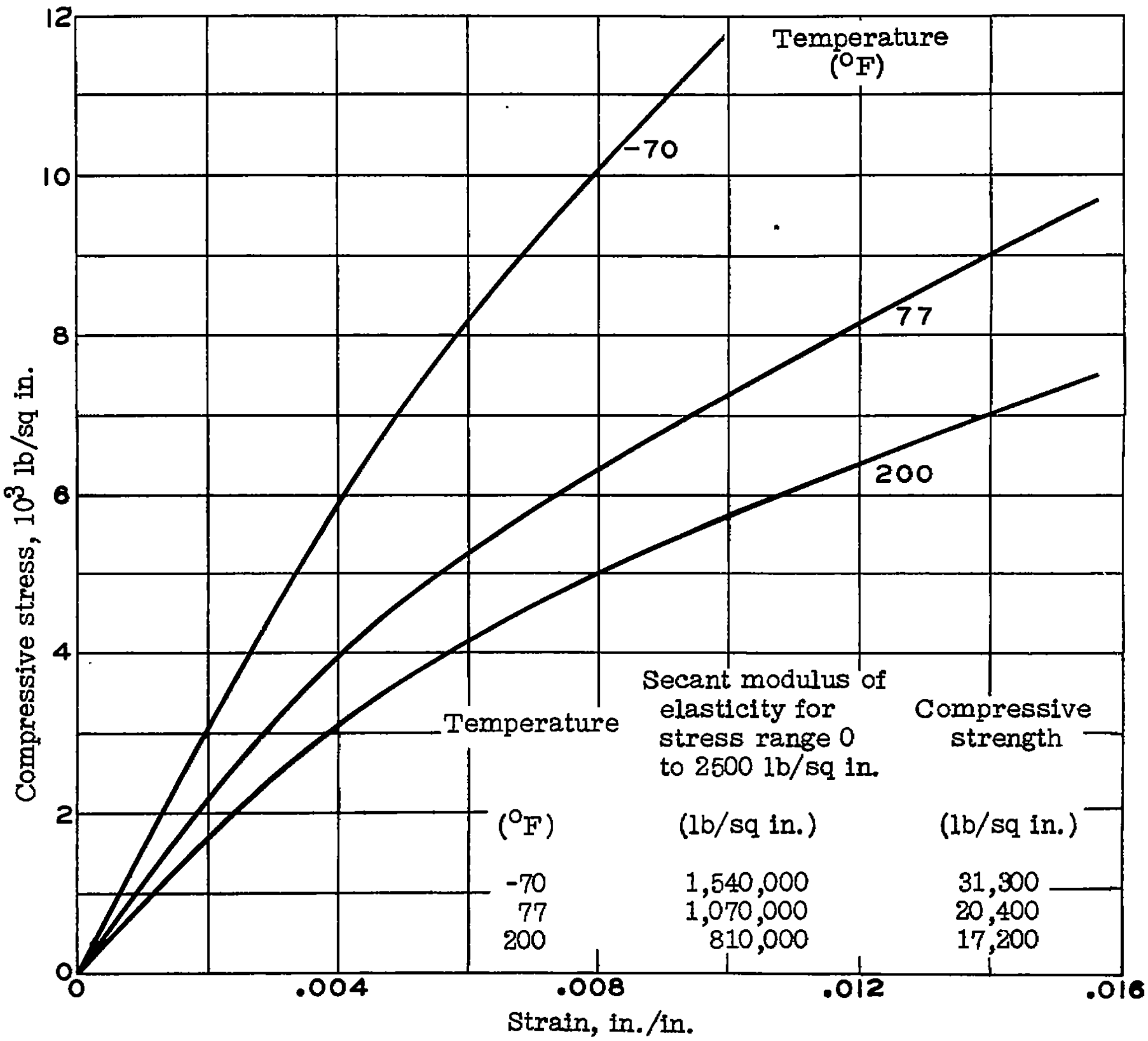


Figure 22.- Compressive stress-strain curves of high-pressure grade C phenolic laminate W2. Lengthwise specimens.

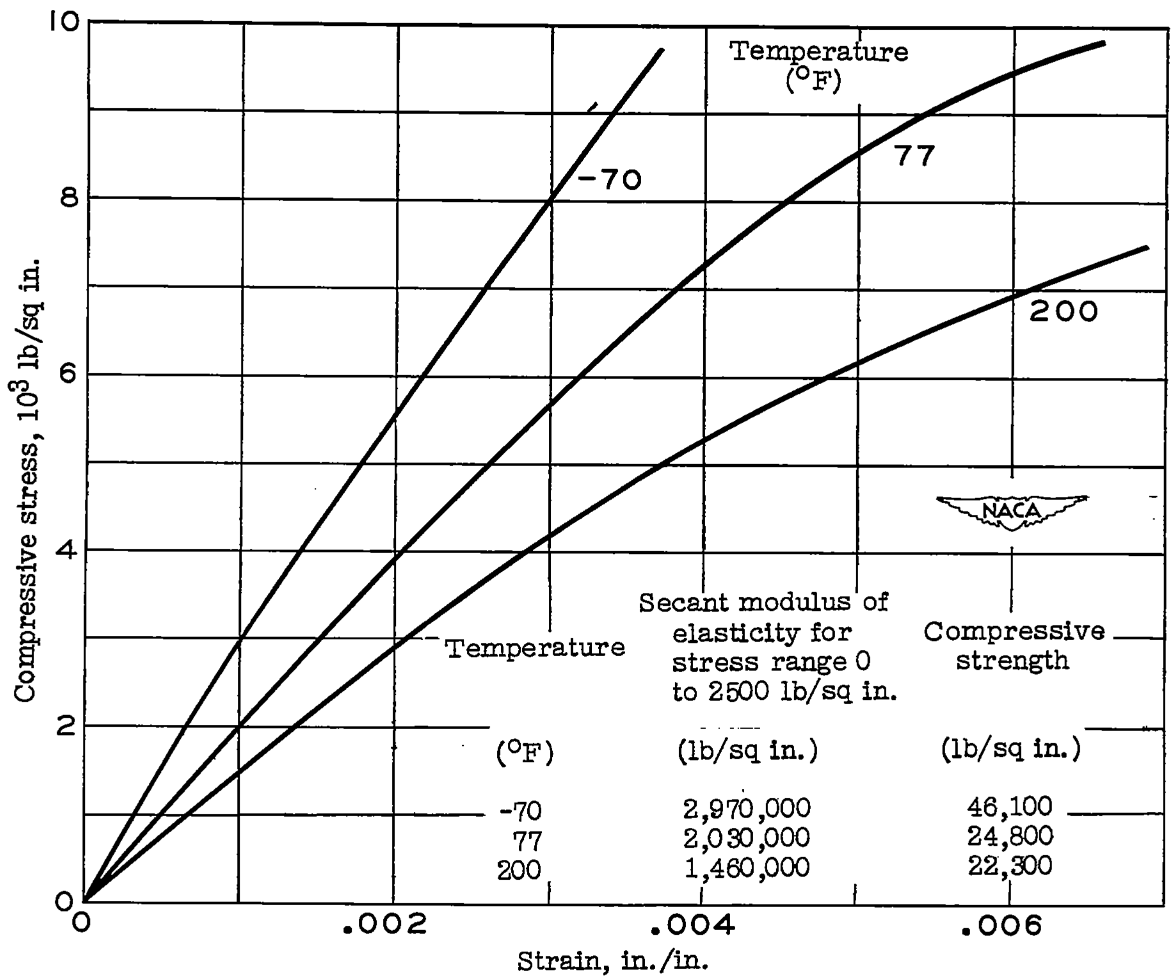


Figure 23.- Compressive stress-strain curves of rayon-cotion-fabric phenolic laminate Z2. Lengthwise specimens.

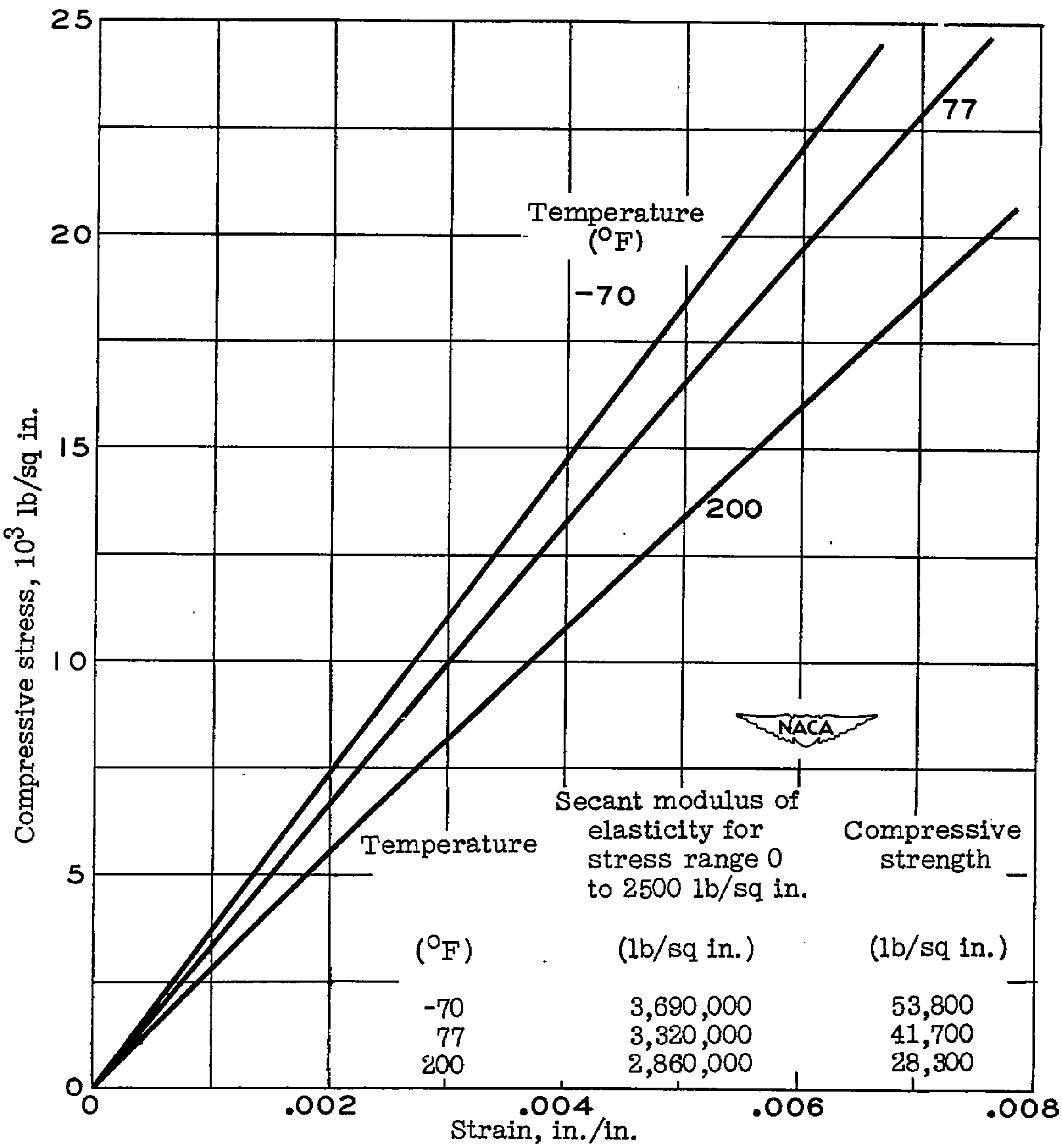
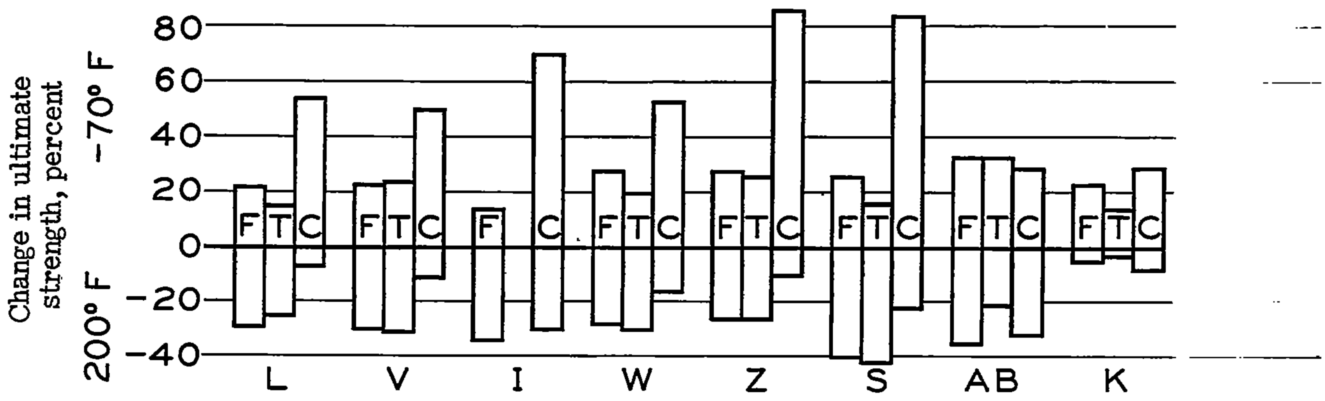


Figure 24.- Compressive stress-strain curves of glass-fabric unsaturated-polyester laminate AB2. Lengthwise specimens.



Designation	Type of laminate
I	Grade C phenolic
K	Asbestos-fabric phenolic
L	Low-pressure cotton-fabric phenolic
S	High-strength-paper phenolic
V	Low-pressure grade C phenolic
W	High-pressure grade C phenolic
Z	Rayon-cotton-fabric phenolic
AB	Glass-fabric unsaturated-polyester

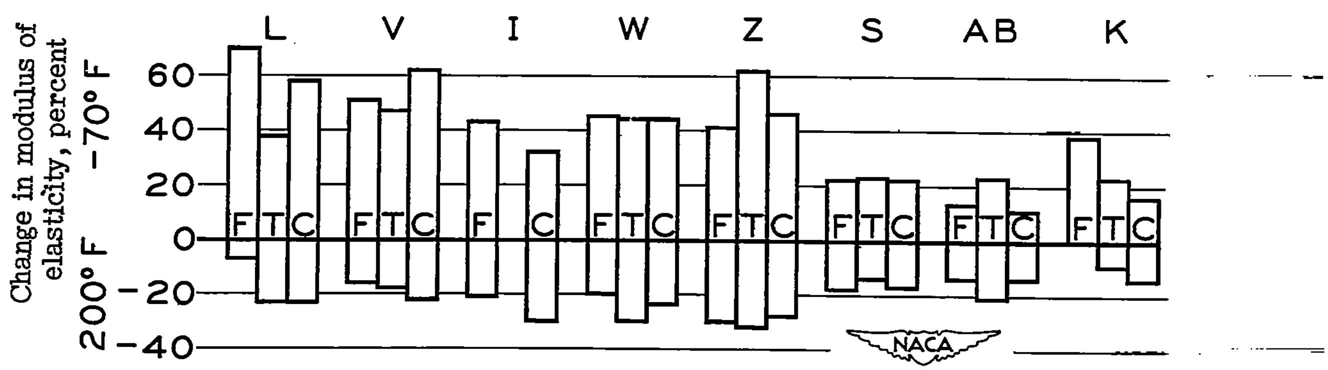


Figure 25.- Comparison of changes in flexural (F), tensile (T), and compressive (C) properties of laminated plastics with temperature.

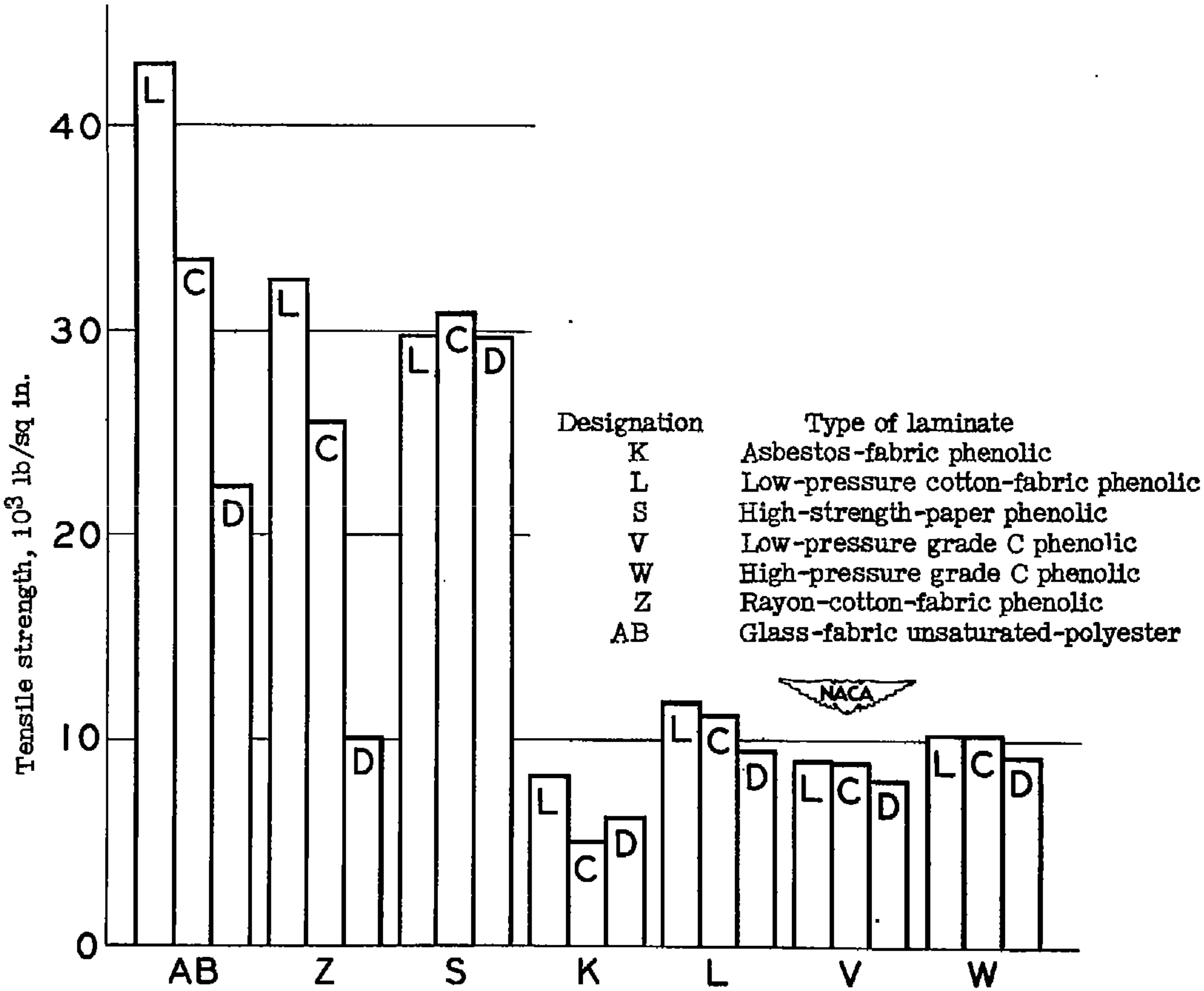


Figure 26.- Tensile strengths for lengthwise, crosswise, and 45° diagonal directions of $\frac{1}{8}$-inch-thick laminates.

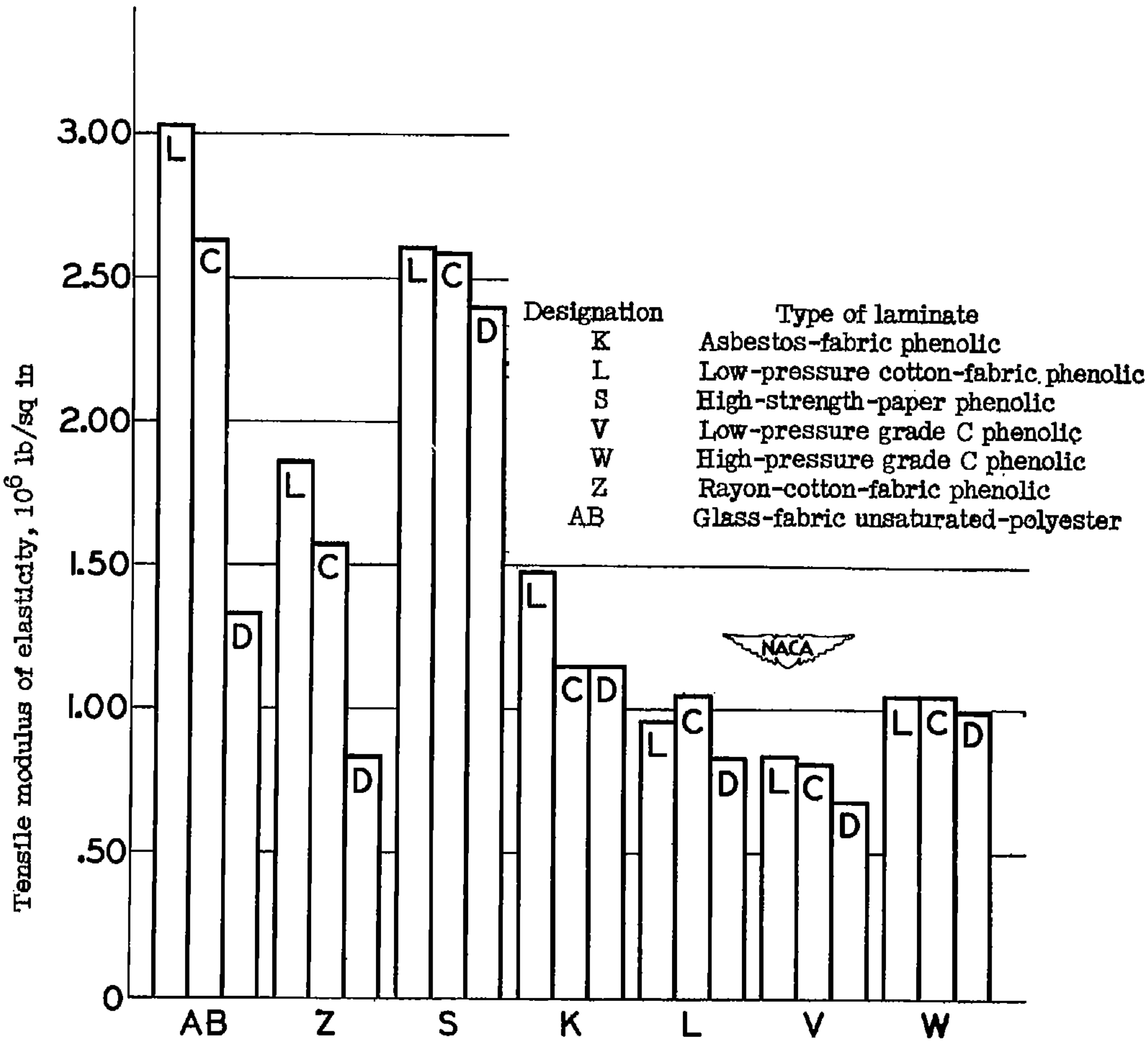


Figure 27.- Tensile secant moduli of elasticity for lengthwise, crosswise, and 45° diagonal directions of $\frac{1}{8}$-inch-thick laminates at 77° F. Stress ranges: 0 to 5000 pounds per square inch for AB, Z, and S; 0 to 2500 pounds per square inch for K, L, V, and W.

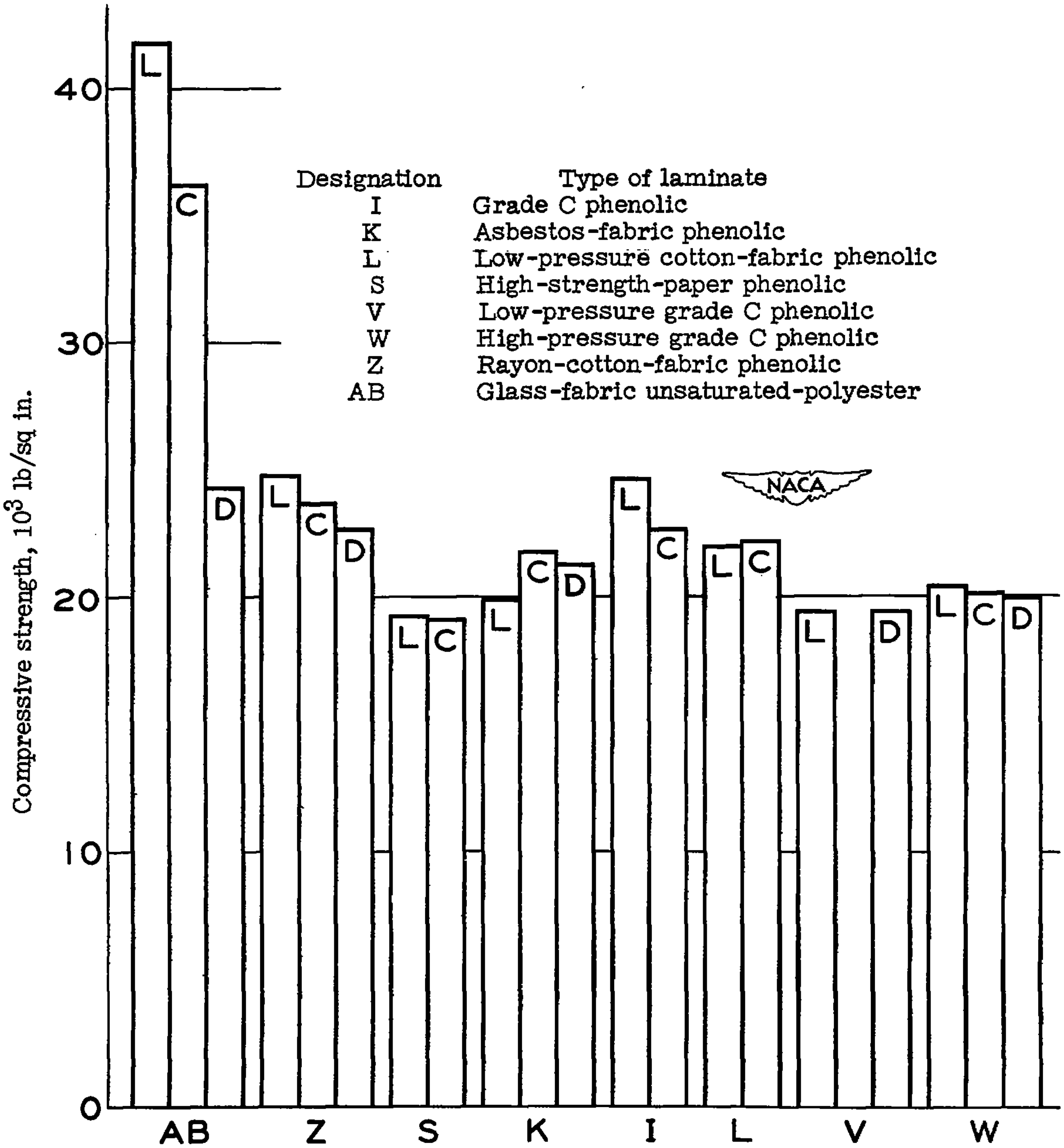


Figure 28.- Compressive strengths for lengthwise, crosswise, and 45° diagonal directions of $\frac{1}{2}$-inch-thick laminates at 77° F.

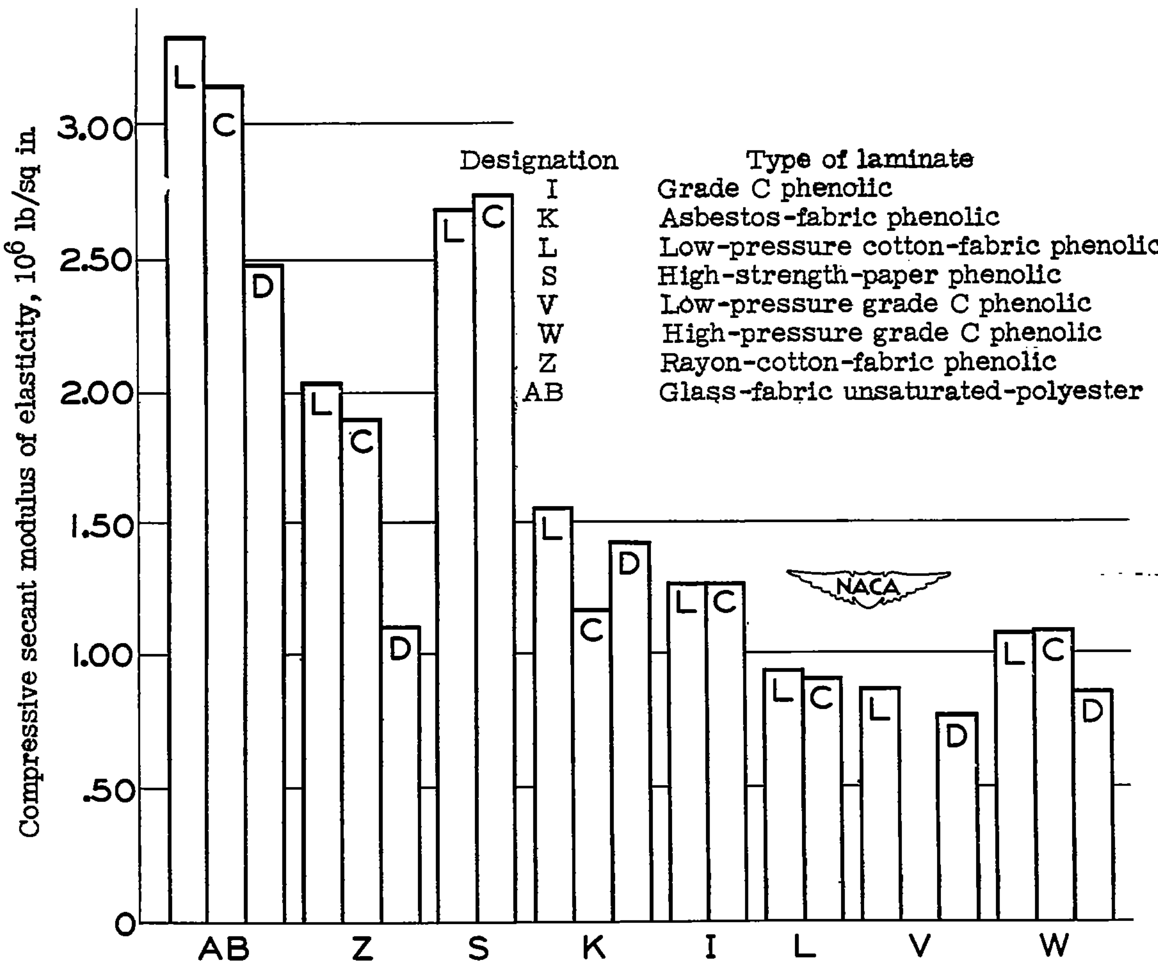


Figure 29.- Compressive secant moduli of elasticity (0 to 2500 lb/sq in.) for lengthwise, crosswise, and 45° diagonal directions of $\frac{1}{2}$-inch-thick laminates at 77° F.